

Incorporating and measuring social equity in transit service allocation

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Abstract

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Transit accessibility is evaluated against theories of equity and social justice. Legal and ideological justifications are used to establish a baseline of “who matters” in equity analyses. A generalizable methodology for calculating accessibility using the general transit feed specification (GTFS) is established and demonstrated. The analysis finds that aggregating various socio-economic and demographic factors into a single index masks relationships between accessibility and each individual factor. For transit services operated by King County Metro in Washington State, a strong, positive relationship is found between accessibility and decreasing income. No significant relationship is found between accessibility and minority populations. A strong, negative relationship is found between accessibility and disabled populations. It is argued that Metro’s policies governing the allocation of fixed-route transit service should account for people with disabilities. Drawing upon various theories of equity, a framework for evaluating the equity of disparities in accessibility between groups is proposed.

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1 Introduction

1.1 Study Context

“Equity” is an oft-spoken and value-laden term that has found itself commonplace next to policy proposals and political activism alike: equity for children, equity for military women, equity for students, equity for English learners, wage equity, equity for entire continents, and, simply, “full equity now!” are just a few examples demonstrating the term’s pervasiveness. It has taken on a life of its own, and though it is not necessarily detached from its definition, its ubiquitous use certainly implies a singular and undebatable meaning. It seems difficult to conceive that answers to the question “what constitutes equity?” could be different from each other. In fact, though, equity simply means fairness. It is easy to ask “what is fair?,” and it is easy to conceive that answers to *this* question will vary from person to person, for each has his or her own conception of fairness. In 2010, the King County Council in Washington State formally defined equity as “full and equal access to opportunities” that enable people to attain their full potential.¹ The definition embodies one of a number of conceptions of equity, and King County’s executive departments have been directed to work towards achieving this sort of equity throughout the county.

As one of the largest arms of the county government and the largest provider of public transit in the Puget Sound region, King County Metro Transit (Metro) has a significant role to play in this mission. “Access to opportunity” partly resides in the sheer ability to reach various destinations. In this sense, “opportunity” can be defined in a number of ways: a job, health care, education, visiting friends and family, and recreation are a few examples. Not long ago, the distance one

¹ King County Ordinance 16948, October 11, 2010.

could travel by walking, biking, or riding a horse defined the number and types of opportunities one could reach. In terms of day-to-day travel, the development of streetcars, motorbuses, and ultimately, the private auto and associated roadways vastly expanded the opportunities available to most people. Urban development patterns conformed to the possibilities created by widespread auto ownership, but some people were left behind. The decline of public transit and the development of a transportation network that grants those with automobiles the largest number and types of opportunities necessarily means that those without the means to own and operate an automobile have less access to opportunity. The disparity increases even further when considering those who cannot even walk or bike on their own. In this sense, public transit is a social service, aiming to increase to the greatest extent possible the opportunities available to “the other half,” to use Jacob Riis’ famous moniker.

In broad terms, this paper examines Metro’s function in achieving social equity, focusing on a particular policy document that explicitly incorporates social equity in decisions affecting the allocation of transit service throughout the county. This set of policies, the Service Guidelines, succeeded the 2010 ordinance defining social equity and stated that considerations thereof should determine, in part, the levels of service provided on transit routes. Four years into its implementation, some of the Guidelines’ component policies, including the one pertaining to social equity, are under review by a Service Guidelines Task Force.² The mandate does not specify goals, nor does it reveal the impetus behind its formation, but the task force will help shape policy revisions, including those pertaining to social equity.

² King County Ordinance 17941, November 17, 2014

The Guidelines, their revisions, and the resulting impacts to social equity are pertinent in light of the continuous service cuts that have occurred since the onset of the great recession in 2008. A deep cut occurred in September 2014, and three more rounds of cuts were stopped only by council action to alter policies governing budget reserves. Residents of the City of Seattle also approved an additional sales tax to stave off cuts to service primarily within city limits. Since Seattle service will be saved (and even enhanced), these additional investments have the potential to alter at least the perception of the county-wide equity of the Metro system.

1.2 Research Proposal

This paper will explore social equity, its general relationship to transportation, and its specific relationship to public transit. It will attempt to answer three questions, each of which will be briefly discussed separately here.

- **How should social equity be incorporated into Metro’s Service Guidelines and the resulting determinations of transit investments?**

This question is tightly bounded to explore only methodological changes to the Guidelines’ existing framework. The exploration will focus on determining which socioeconomic factors *should* be considered when accounting for equity. The discussion branches to explore alternatives to the current methods of determining the social equity “score” component of setting service levels in the Metro network.

- **To what degree does access to opportunity via transit vary by location and by relative disadvantage within King County?**

Since access to opportunity is such a core part of King County’s definition of equity, the paper proposes a methodology to generate data that can be used to evaluate the equity of the network. It draws heavily on existing literature pertaining to the measurement of transit accessibility and

uses methods that will be familiar to those who follow accessibility research. The methodology is data-intensive and uses recently-developed tools yet on the cusp of being usable in practice.

- **To what degree can network changes affect access to opportunity among varyingly disadvantaged groups, and how can differences among groups be analyzed?**

The ability to holistically evaluate the impacts of a network change is perhaps the most sought-after in transit planning for equity. The paper's methodology generates data about accessibility both before and after an actual network change. Drawing on the literature, a framework is established to enable an evaluation of the equity of the change. The generated data is then evaluated within this framework. The purpose is not to pass a judgment of whether or not the change was equitable or inequitable, but rather to demonstrate how such an evaluation could occur and how judgments could be made given a particular conception of equity.

1.3 Study Purpose

Establishing a clear understanding of different conceptions of equity is a primary purpose of this paper. As will be established, myriad opinions about equity and justice exist, each with a deep philosophical lineage. Others have likely done a better job of clearly explaining the nuances of various conceptions of equity (see, for example, Le Grand (1991, 2006) for concise expositions on the topic). Clarity in language and message, which is often lacking even in the literature, can only help equity advocates and shield their goals from attack.

A second major purpose is to incrementally advance accessibility analysis by combining aspects of some recent studies and recently-developed tools. These tools are on the cusp of being useable by transit planners in an office environment, but additional work is yet required. By demonstrating a methodology that uses readily-available data and off-the-shelf tools, it is hoped that this work can help span the chasm between academic research and real-world practice. An

impetus to develop easy-to-use tools for planners already exists. The methodology used in this paper is far from refined, but a future tool that uses this methodology as its backbone could, as part of its development cycle, incorporate refinements already present in the literature.

Lastly, this paper intends to influence how Metro incorporates social equity into transit allocation decisions, how it evaluates the equity of the system, and how it evaluates the equity of changes to the network. Further to this, it may influence the work of the Service Guidelines Task Force as it discovers that the Guidelines compose but one part, and perhaps even a *minor* part, of how equity is addressed at Metro. In practice, the Guidelines may not have a substantial effect on social equity when compared to the other efforts Metro undertakes. In that light, the extreme attention paid to the Guidelines' methodology to "score" social equity may be misplaced; broadening the Guidelines to include and formalize these other processes could be more fruitful than any methodological tweaks the Service Guidelines Task Force may recommend.

2 Background

Social equity and justice are central themes of this thesis; as such, a discussion of their philosophical roots follows. This section visits the major philosophical conceptions of justice, the roots of social equity, and the various dimensions thereof. It then proceeds to a discussion of broad applications of the principles of justice and social equity, narrowing the focus first to the provision of infrastructure generally and then to transportation and transit service specifically. Next, a discussion of the role of law and policy in the administration of equity is used to establish a basis for the achievement of social equity in a representative republic. Lastly, the application of various laws and policies aimed at achieving social equity in King County's transit service is examined.

2.1 Philosophy, Theory, and Principles

What is justice? Broadly speaking, conceptions of justice can be split into two categories: retributive and distributive. The former is concerned with punishment for wrongdoing and is not applicable in this paper's context. The latter deals with the distribution of goods in a society and is of principle importance to the present discussion. Myriad theories based on various philosophical underpinnings attempt to define the conditions by which any given distribution of goods can or cannot be considered just. Solimano (1998) divides these into three broad categories: liberal, socialist, and libertarian, and this discussion proceeds along these lines.

2.1.1 Liberalism

Liberal schools of thought can be divided in various ways. Tomasi broadly separates them into two traditions: free market and democratic. The former, also referred to as classical liberalism, is based on a concern for private economic liberty. The latter is concerned with social justice, and he lumps many stripes, including modern liberals, liberal democrats, and egalitarians, into a "left

liberal” bin (Tomasi 2012, xix). Solimano makes divisions between the utilitarianism of Mill, Smith, Bentham, Edgeworth, and others, and his characterization of modern philosopher John Rawls as contractarian and being influenced by Locke, Rousseau, and Kant (Solimano 1998, 15). These divisions are somewhat fluid, and not all of any particular early thinker’s ideas are necessarily included in each of the later thinkers’ theories.

Utilitarianism uses the maximization of social utility, or total benefit, as a moral guideline for action. It contrasts with other theories in that it is not chiefly concerned with the distribution of the benefits among members of society, though it can be seen (under Bentham) as at least theorizing that benefits will be distributed such that most will have an adequate share (Solimano 1998, 15-16).³ Rawls takes up this argument and rejects the idea that total benefit can be seen to offset the hardships experienced by the few; these hardships must be rectified to achieve justice. This forms part of the basis for his theory of “justice as fairness” (Rawls 1971). This work opened a chasm in liberalism and established the modern roots of the social equity movement.

Rawls’ groundbreaking theory, first introduced in 1971, broke down the utilitarian tendencies of modern society. He sought a moral theory for the design of institutions based on principles that would nullify “the accidents of natural endowment and the contingencies of social circumstance” (Rawls 1971, 15), in other words, differences in genes and people’s starting positions in life. Rawls focuses on institutions, not necessarily the results they produce: outcomes resulting from just institutions are themselves just (Rawls 1971, 8). He relies on people, via a deliberative process, to decide upon the principles governing institutions, providing a link to social contract theory. He constructs a hypothetical *original position*, in which those deciding the principles

³ See also footnote 3 in Solimano 1998.

upon which society will be based are stripped of certain knowledge about themselves; they are, however, endowed with a sense of justice and are strictly rational actors. They will seek to maximize their position, but they lack any knowledge of their own attributes, talents, or status in society. Therefore, they will have a certain regard for how they *may* end up in a society governed by the principles they choose. The negotiation among parties in the original position is *fair*, and so the outcomes are also fair (Rawls 1971, 11).

Rawls claims that parties in the original position, behind his veil of ignorance, would choose two specific principles to govern institutions and all future agreements from a set of provided principles; the parties do not *deduce* the principles within the original position (Rawls 2001, 83).

These two chosen principles, as restated in a revision of his original work, are:

Each person has the same inalienable claim to a fully adequate scheme of equal basic liberties, which scheme is compatible with the same scheme of liberties for all; and

Social and economic inequalities are to satisfy two conditions: first, they are to be attached to offices and positions open to all under conditions of fair equality of opportunity; and second, they are to be to the greatest benefit of the least-advantaged members of society (the difference principle). (Rawls 2001, 42-43)

The principles are lexically ordered, such that any arrangement meeting the second principle must not violate the first principle. Basic liberties are thus inviolable, and Rawls includes among these certain political liberties (the freedom of speech, for example) and limited economic liberties (the right to own personal property and the freedom of occupational choice). Rights to the means of production are *not* included, but they may still be justified based on historical and social conditions (Rawls 2001, 114).

Fair equality of opportunity is similarly lexically before the difference principle. This provision is meant to correct the “defects” of *formal* equality of opportunity, which Rawls conceives of as careers open to talents in the system of natural liberty. In contrast, *fair* equality of opportunity

demands that two people with equal natural endowments and the same willingness to use them should have equal prospects of success, no matter their background (Rawls 2001, 43). Society must be arranged such that nothing else matters. Once these conditions are met, the difference principle can apply. This principle is interpreted as meaning that inequalities between people can be just, but only if those inequalities lead to benefits for the least advantaged in society. It has been the driving force behind the social equity, or social fairness, movement.

Tomasi attempts to bridge the chasm between free market and democratic liberals. He views a primary distinction between the two in terms of the placement of economic liberty, and particularly private ownership of the means of production, in the rank order of things about which we should care. He begins with the Lockean idea of self-ownership with the resulting moral rights to property (both personal and the means of production) that follow. However, he does not base this conception of “thick” economic liberty on Locke, but instead on the individual’s execution of his moral powers. Those moral powers have been defined in various ways throughout philosophical history, but Tomasi follows Rawls by defining them as the ability of individuals to set out life plans for themselves (self-authorship) and the recognition that others also have this right and ability (Tomasi 2012, 40). For Tomasi, economic liberty is a necessary condition to be able to execute moral powers. But he does not go so far as to say this is the *only* thing that matters, as classical liberals are apt to do. Instead, he states that “the very status of people as responsible self-authors *may be threatened by conditions of extreme need*” (emphasis added) (Tomasi 2012, 99). This need can arise from the lottery of natural endowments and the accidents of social circumstance, the very things which Rawls’ theory seeks to nullify. Thus, the state must have the requisite power to protect each individual’s right to self-authorship.

Rawls is not without his critics; indeed, no philosopher is. For instance, egalitarians, which advocate a strictly equal system, criticize Rawls' theory for allowing inequalities in society (Smith 1998). With that, I turn briefly to socialism.

2.1.2 Socialism

The conception of justice in egalitarian forms of society differs significantly from the liberal tradition. Socialism in the traditional sense derives from Marxism, which is concerned with economic equality among all members of society. Set as a critique against capitalism in which the value of goods produced by labor is exploited by those owning the means of production, Marxism argues against the private ownership of capital. Following many critiques of Marxism's theoretical shortcomings and some abject failures in real-world applications, "reconstructed" Marxism, drawing on Dworkin, seeks to categorize resources into two types. One includes those resources that are *external* to the individual (capital, land, real estate, or financial assets), while the other includes resources that are *internal* (talent, skills, attitude toward risk, ambition, etc.) (Solimano 1998, 19). This, however, presents problems of distributional outcomes, for *internal* resources cannot viably be redistributed (Solimano 1998, 20). Suffice to say that egalitarian models emphasize equal outcomes, and justice in society can only be determined by how closely one person's outcomes resemble another's.

2.1.3 Libertarianism and Critiques of Social Equity

Libertarian thought is essentially devoid of any consideration of distribution in its conception of justice. Instead, individual freedom, self-ownership, and the lack of interference from the state are its hallmarks. Nozick, a colleague of Rawls, is perhaps the most prominent recent advocate of libertarianism. Like Locke, Nozick believes "things come into the world already attached to people having entitlements over them" (Nozick 1973, 56). Any interference by an external actor

to forcibly or coercively take from one person and give to another is unjust, with one major exception: the rectification of historical injustice (as with slavery) (Nozick 1973, 126). Even something as widely accepted as the income tax gives someone else a right *in* another person and their labor. Nozick also attacks Rawls' attempt to nullify natural endowment, saying that attributing *everything* noteworthy about a person (their talents, diligence, persistence, aims, and goals) completely to external factors (such as genes and social circumstance) is risky for a theory wishing to buttress human dignity and self-respect. He further claims that Rawls' theory is inconsistent, in that it allows for inequalities to exist that are due, at least in some interpretations of Rawls, to the genetic lottery, one of the very things the theory attempts to nullify (Nozick 1973, 109). In other words, a person who desires to advance the social good desires to do so specifically as a result of his genetic makeup and social circumstances; he has no control over this. Yet he is rewarded unequally for it, and this, according to Rawls, is just. One of Nozick's strongest conclusions is that the difference principle represents "an agreement to regard the distribution of natural talents as a common asset and to share in the benefits of this distribution whatever it turns out to be" (Nozick 1973, 123) which is, in essence, the absolute destruction of liberty.

Hayek attacks the notion of "social" justice as farcical in that only things of human design (or individual action) can be just or unjust. He further claims "there is no need morally to justify specific distributions (of wealth or income) which have not been brought about deliberately, but are the outcomes of a game that is played because it improves the chances of all" (Hayek 1976, 117). Justice is concerned, therefore, not with distributions, but with rules of conduct or behavior in "the game." Interestingly, Tomasi argues that Hayek is incorrect in stating that the spontaneous order of individual activity in the market is not of human design (Tomasi 2012,

142). If it *is* of human design, as he argues, outcomes can be judged as just or unjust, and distribution becomes important.

2.1.4 Other Concepts

In addition to the ideas already discussed, Rawls (1971), Khisty (1996) and others bring forward two additional conceptions of distributive justice: maximizing the average benefit while observing a minimum benefit for all (a floor), and maximizing the average benefit while observing a maximum range between the best off and worst off (a range constraint). (These differ from maximizing the floor, which is Rawlsian, and maximizing the average, which is utilitarian.) The first of these would view as just *any* distribution of goods so long as each has a certain agreed-upon minimum. (One assumes some preservation of basic liberties, however defined, is already met.) The second views any distribution as just so long as the difference between, for example, the richest and the poorest, is constrained to an agreed-upon maximum, likely through government intervention and redistribution.

Which ideas are the best? In Khisty's words, "there is no single way of defining justice and no single theory of justice that will satisfy everyone" (Khisty 1996, 95). Curiously, in a real-world experiment placing people in Rawls' original position, 78% of groups chose maximizing the average with a floor as the appropriate principle of distributive justice (Zajac 1995, 113), departing from Rawls' intent to maximize the floor. As long as people are free, opinions about which principles and conceptions of justice are appropriate will vary among individuals, groups, and societies, and the debate over what constitutes justice and fairness will continue. Practical remedies to this problem have been implemented in the real world; these will be discussed anon. To be able to move forward, though, it must be acknowledged that this paper deals primarily with issues of the fairness of distributions (distributional equity). But the idea that the

achievement of a particular conception of distributional equity is a responsibility of government relies on the acceptance that it is fundamentally fair for government to coercively take goods from one group and give them to another, a notion Nozick and libertarians in general reject. This is an important and debatable point, but this paper is not about philosophy. For the present discussion to continue, it must be accepted that the governmental distribution of goods, in and of itself, *can* be a fair and just act.

2.1.5 Equity and Determinations Thereof

I have been using the term “equity” without discussing some of the nuance in its meaning. The literature does not always clearly define the term, and there is often confusion or ambiguity in its use (Manaugh and El-Geneidy 2012, Murray and Davis 2001, Le Grand 1991). “Equity” resembles “equality;” that they sound similar and derive from similar Latin roots (*aequālis* and *aequus*, respectively) can confuse their meanings. Careless handling of the two words, particularly when used interchangeably, does not serve to advance the goals of equity advocates, but instead merely confuses that which is being pursued. Precision of language is required to ensure ideas are communicated accurately.

The Oxford English Dictionary defines equity as “the quality of being equal or fair; fairness, impartiality; even-handed dealing” (OED, s.v. “equity”). Unfortunately, this definition helps only marginally in making a distinction between “equality” and “equity,” so an examination of the word “equal” is warranted. Equality is “the state of being equal, especially in status, rights, and opportunities” (OED, s.v. “equality”), and “equal” is synonymous with “same,” a word used in Rawls’ first principle of justice; “equal” was used in his original rendering as the way in which basic liberties would be distributed in society. This contrasts with the difference principle, which does not reference “equality,” “equal,” or “sameness,” but instead stresses the potential

existence of *differences* among what people get (in terms of primary goods).⁴ We can therefore interpret “equity” as including some manner of difference in the distribution of goods, but that these disparities are judged (by society) as being fundamentally fair. If the differences are fair, then they are just.

Then, what is meant by “social” equity? Simply put, it is equity “of or relating to society” (OED, s.v. "social"). Another term, “social justice,” is used throughout the literature either next to or in place of “social equity.” In Rawls’ conception of justice as fairness, these two terms are at least synonymous, if not identical in meaning. In short, “social equity” is what is deemed fair by society. It follows that describing something as both “fair and equitable” is redundant; similarly, if Rawls’ conception of justice is the context, the phrases “equity and social justice” and “fair and just” are also redundant.

For Khisty, equity refers to “the ethical desirability of distributing benefits (or wealth) among groups of individuals and to the corresponding injustice caused by substantial uncompensated losses” (Khisty 1996, 94). He and others cite two major types of equity: vertical and horizontal. Horizontal equity is concerned with the impartial treatment of individuals in similar circumstances (Khisty 1996), or equal treatment for equals (Frederickson 2010). Vertical equity is concerned with the distribution of benefits among different classes of people (Khisty 1996), often resulting in deliberately *unequal* distributions based on a chosen criteria (Manauh and El-Geneidy 2012). These types of equity coexist; one does not choose between them. For instance, a food stamps program may distribute benefits based on a needs test (income), drawing on the

⁴ Rawls’ second principle (of which the difference principle is a part) does establish “fair equality of opportunity,” but this is a caveat that must be satisfied for any unequal distribution of goods to be considered just. This clause is not principally concerned with the distribution itself, and it does not mandate an equal distribution.

vertical type of equity, but ensuring people of equal incomes receive the same dollar amount of food stamps would be necessary to satisfy horizontal equity. Horizontal equity may thus be thought of as equality among equals, or equality (of something) within a defined group. Litman (2014) divides vertical equity into two additional types. The first is vertical equity with respect to income and social class, while the second is vertical equity with respect to need and ability. The former is broader, and is generally equivalent to social equity, while the latter is more detailed and requires the consideration of specific needs within a particular context.

The literature is rich with factors that may be considered when making determinations of what is equitable (fair) and what is not (Blanchard 1986, Beatley 1988, Lucy 1988, Jones and Lucas 2012, Krumholz 1982, Le Grand 2006, Murray and Davis 2001, Levinson 2002). Table 1 lists these concepts; those that appear in the same row represent similar or related ideas. They embody aspirations and/or concepts to be taken into consideration when evaluating programs and policies. Normative writing will define fairness in terms of one or more of these factors. However, fairness (and therefore justice) is determined by agreed-upon standards of the group performing the evaluation (Blanchard 1986), and different standards likely will result from different groups (Beatley 1988, 223); in the broadest sense, the people performing the evaluation can be taken to mean “society,” but in the representative republic of the United States (or any of its component states), “government” is the most likely actor to make a determination, at least in terms of an *enforceable* one. While this paper will not take the time to discuss each factor here, many of them will appear and receive treatment in other sections as they relate to the literature and this study.

Table 1. Factors of Equality and Equity

Equal share	Equal benefit		
Equal sacrifice	Equal effort	Equal payment	Equal burden
Equal chance	Equal opportunity		
Equal access	Equal representation	Equal influence	Equal participation
Equal outcome	Equal result	Equal impact	Equal compensation
Rectification of injustice	Rectification of inequality		
Equal Need	Ascription		
Ability to choose	Preferences	Locational choice	Demand
Willingness to pay	Money invested		
Ability to pay			

Sources: Blanchard (1986); Beatley (1988); Lucy (1988); Levinson (2002); Jones and Lucas (2012); Krumholz (1982); Le Grand (2006); Murray and Davis (2001).

In Rawls' formulation of justice, the requirements of fairness are established in the second principle. However, Blanchard (1986) critiques Rawls' principles as being too vague and not providing a useable formula for how goods are to be distributed. He proposes a framework of norms, modified from Hirsch, on a spectrum from strict equality to deliberate inequality that could be used to evaluate the relative fairness of policies. After the distributional consequences of a policy are established, they may be evaluated in terms of one or more norms; a single policy may use multiple norms in how determinations of who gets what are made. This "fairness analysis" makes explicit the value implications of the policy and exposes the ambiguity of determining what is fair (Blanchard 1986, 52).

Thus far, language has focused on determining what is fair and unfair, equitable and inequitable, just and unjust. However, this risks presenting evaluations of programs and policies as a false dichotomy. Perfect fairness in the real world is likely unachievable. Therefore, it may benefit us to think in terms of a "spectrum of fairness." The questions we would therefore ask include: Does a policy or project increase or decrease overall fairness in society? Does it move us toward or away from a just society (based on the chosen standards)? Apart from being qualitative in

nature, at least initially, the use of such a spectrum presents other problems as well as advantages. On the one hand, it may allow advocacy of a project that only marginally increases fairness when other options exist that could do more. On the other hand, it allows fairness to be weighed against other societal values (including efficiency and economy). For example, one policy may increase fairness only marginally, but cost significantly less than an alternative that achieves significant gains in fairness; this policy may be favored over others. Being able to evaluate shades of fairness is likely more practical than asking whether the policy or program itself is singularly fair or unfair.

Most of this discussion has at least implied that fairness is focused on outcomes – distributions of goods. Other factors, however, exist that precede the distribution, and these pertain to Rawls' primary domain: institutions. Equal chance, opportunity, access, and representation can all be viewed through the lens of *the processes* that institutions use to arrive at decisions that affect distributions of goods. A conception of fair equality of opportunity demands equal access to planning and decision-making processes (Levinson 2002, 179), and this follows Rawls directly. Consultation with the population is necessary from an equity perspective (Sanchez and Brennan 2007, 8, Bullard and Johnson 1997, 3). But influence and political power is not equally distributed; this may necessitate steps to ensure all groups can effectively participate (Beatley 1988, 221). Among practitioners, there appears to be agreement that social equity depends on including citizens in the planning process from the very beginning (Federal Transit Administration 1995). *Formal* equality of opportunity differs from *fair* (or *effective* or *substantive*) equality of opportunity; the former concerns whether or not equality of opportunity is codified in law, policy, and procedure, while the latter concerns whether or not equality of opportunity is actually achieved (Solimano 1998). Fair equality of opportunity can of course be

applied more broadly; in the Rawlsian sense, it is meant to correct the “defects” of formal equality of opportunity in that equals ought to have the same chance of success (at something) (Rawls 2001, 43), which can be thought to include success in influencing decision-making. Thus, the fairness of the process, as well as that of the outcomes, matters. The exact forms processes take may vary, and it may be justly abstracted in a representative republic whereby the decision-making of elected officials represents fair access of the general public to the process. This depends on equal access to vote and officials’ being elected fairly. The debate over whether or not these conditions are met in the United States exceeds this paper’s scope, but the outcome of such a debate would directly affect the degree to which public servants should advocate particular social policies.

Lastly, a brief discussion on the meaning of “outcomes” is warranted. There may exist a tendency to view outcomes only in the sense of “who benefits and how.” Social equity, however, depends on an appropriate (fair) distribution of both the benefits *and* burdens of social cooperation (Rawls 1971). Any project or policy is bound to produce benefits for some and burdens for others, often thought of in terms of monetary payments and credits. The phrase “who gets and who pays” embodies this concept, and a holistic equity evaluation must include an analysis of how the distribution of benefits among groups compares to the distribution of burdens among the same groups. Such a quantitative analysis will reveal the facts of a distribution, but it will not determine, in and of itself, whether or not the distribution is fair. An evaluation of the distribution against one or more norms is required, as previously discussed.

2.2 Equity and Transportation Infrastructure

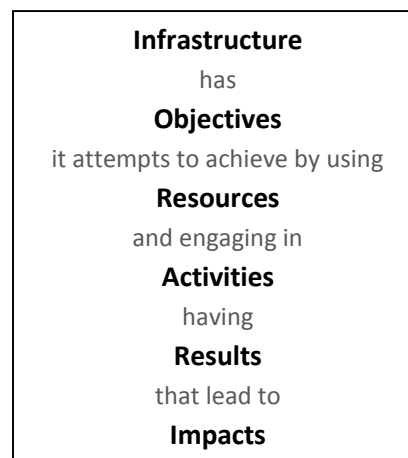
Transportation and equity can be perceived as a “bundle of tangled elements” that includes land use, the environment, and health as interrelated factors (Mercier 2009). Most of these elements

are beyond the scope of this paper, but it is important to keep in mind that transportation affects equity in many ways. Sanchez and Brenman (2007) state transportation equity refers to “a range of strategies and policies that aim to address inequities in the nation’s transportation planning and project delivery system” (7). To tie principles of equity to infrastructure planning, Beatley (1988) discusses how conceptions of equality can be applied to decision-

making, concluding that “there is a strong need for careful and politically inclusive debate about public infrastructure along equity dimensions” (224). Using the framework as adapted in Figure 1, Lucy (1988) attempts to normatively operationalize equity in terms of the distribution of benefits and costs (burdens), explicitly taking need, demand, preference, and willingness to pay into account.⁵ A three-part process in determining infrastructure investments writ large includes determining the facts of the current distribution of benefits and burdens (Table 2), a deliberation of which equity concepts should apply to which services, and a comparison between services to aid in choosing which projects are to receive investment (Lucy 1988, 233-7). Including an equity impact statement in benefit-cost analyses as well as providing equal access to planning and decision-making processes can enhance equity (Levinson 2002).

Though the equity concepts that apply to infrastructure investment decisions are relatively established, Martens, Golub, and Robinson (2012) claim “there is no clear definition, in theory or practice, of what constitutes a fair distribution of benefits from transportation investments”

Figure 1. Framework of Equity Analysis. Adapted from Lucy (1988)



⁵ Blanchard (1986) questions the legitimacy of Lucy’s inclusion of demand and preference norms, as these reflect what people want, not what they are entitled to or should justly (or fairly) receive.

(684); this is consistent with Blanchard's (1986) assessment of Rawlsian justice, and it focuses on evaluating *distributions* as opposed to *processes*. Difficulties are encountered, they argue, in applying Rawls' difference principle to the transport good in that it is unclear how differences in access levels would increase total access and how they would benefit the person with the least access (687).⁶ This is, though, a misapplication of the difference principle: for example, differences in income are permitted (under Rawls) not because they increase the *income* of the person with the least income, but rather because they serve to *benefit in some way* the person with least income. Thus, if differences in access produced some form of benefit to least advantaged, they would be permitted under Rawls. Martens, Golub, and Robinson (2012) do, however, state Rawls' principles imply a maximum gap in access between the best-off and worst-off (even though Rawls does not explicitly choose this principle) and defend a distributive approach to transportation on the basis that it is a good in which society places a special value (contrasting

Table 2. Benefits and Burdens of Transportation Projects

Potential benefits	Increase in access and/or accessibility
	Frequency
	Duration (span of service)
	Geographic extent
	Decrease in user fees (subsidy)
	Higher quality service
	Cleanliness
	On-time performance
	Increased enjoyment / life fulfillment
	Decreased pollution (noise, air)
Decreased travel time	
Improved health outcomes	
Social interactions / social capital	
Potential burdens	Decrease in access and/or accessibility
	Increase in user fees
	Lower quality service
	Decreased enjoyment / life fulfillment
	Increased pollution (noise, air)
	Increased travel time
	Physical isolation (barrier effect)
	Health and psychological impacts
	Social exclusion / isolation
	Degradation of personal safety
Responsibility for funding (taxes, fees)	
Displacement via eminent domain	
Displacement via gentrification	

Sources: Bullard and Johnson (1997); Federal Highway Administration (Analyzing Community Impacts); Jones and Lucas (2012); Litman (2014)

⁶ This statement is interesting in light of the assertion of van Wee and Geurs (2011) that access *can* be considered a Rawlsian primary good to which the difference principle would directly apply. It is clear this issue is not settled.

with, e.g., material possessions). In rejecting the difference principle, and arguing primarily from spatial- and mode-based-equity perspectives, they choose one of the other distributive alternatives discussed above: maximize average access while observing a maximum range in differences in access (“maximax”). This contrasts with the alternative of maximizing the average while observing a minimum level of access (a floor); they argue that determining the minimum level would involve “extremely precarious normative judgments” regarding how much access is required (or is sufficient) to enable individuals to pursue life opportunities (i.e. be self-authors or pursue happiness) (Martens, Golub and Robinson 2012). Even though maximax requires a floor constraint to be defined, it is anchored to the highest level of access, and it may be easier (though likely still difficult) to determine the floor in relative, as opposed to absolute, terms.

Due to the nature of the transportation system, the maximum level of access is provided by the automobile. Equity analyses of the transportation system can thus compare the access of people with cars to the access of those without cars (Grengs 2010, Shen 1998). The federal government’s focus on highway building, the displacement of low-income and minority populations it caused, and federal housing policies that encouraged sprawl all contributed to current inequity, including transportation inequity (Bullard and Johnson 1997, 7). Low-income and minority populations “pay the highest social, economic and environmental costs and receive the fewest benefits from an automobile-dominated transportation system” (Bullard and Johnson 1997, 22). The evolution of transportation system also produced disparities among groups in terms of available life opportunities. In the latter half of the 20th century, as suburbs grew, jobs spiraled outward from historical downtowns; the more affluent moved out, leaving poor and minorities in locations with declining access to jobs (Sanchez and Brenman 2007, Hu 2014, Shen

1998). Therefore, in addition to social equity, the rectification of past injustice also stands as a legitimate goal of current transportation planning.

Though analyzing the equity of an entire transportation system is beyond the scope of this paper, a simple and binary distinction can help define transit's role in achieving transport equity.

Following their earlier study and settlement on the maximax principle, Martens and Golub (2014) state the gap in access between *car-owning* and *car-less* households should remain within a specified range. Though this exact differentiation among people will not be used, it serves to highlight that transit exists to increase access for those who cannot use, or have difficulty using, the dominant mode of transportation. In this sense, transit exists to increase transport equity.

2.2.1 Transit Equity

When movement, mobility, and accessibility are the primary units of analysis *as goods*, transit exists as merely one means among many to acquire these goods. The equity of a transit system must therefore be analyzed in the context of the entire transportation network. The appropriate question to ask is “Does the transit system increase or decrease the equity (fairness) of the transportation system as a whole?” In this sense, *equity in accessibility* is the issue in question. To understand transit's role in increasing equity, we must first determine which groups are disadvantaged in terms of accessibility. This is, in essence, a determination of need and ability, following Litman's (2014) conception of vertical equity. The auto-dependent nature of the transportation system does not meet the needs of economically, physically, and socially disadvantaged groups who also happen to suffer a disproportionate share of external costs (Litman 2014). Solutions to rectify this situation, for example the heavy subsidization of transit, therefore support equity (Foth, Manaugh and El-Geneidy 2013, Martens, Golub and Robinson 2012, Murray and Davis 2001, Manaugh and El-Geneidy 2012). In this sense, *any* level of

transit provided to those who need it increases the equity of the entire transportation system.

While this sort of analysis is important, this paper drills one level further down and focuses on the fairness of the distribution of transit accessibility itself.

“For communities that depend heavily on public transportation, the level and quality of transit service in urban neighborhoods compared to that in more affluent suburban areas is often the definitive transportation justice issue” (Jakowitsch and Ernst 2004, 171). Several generalized factors influence this statement. First, suburban areas are more often served by rail than bus service. Second, providing transportation by rail is more capital intensive than is providing it by bus, and bus service is more intensive on the operations side. Third, most federal funding is directed at capital projects, not operating budgets. Lastly, the federal tax scheme, from which transportation funding is derived and distributed, is progressive, while the state and local schemes that fund bus operations are generally regressive (Sanchez and Brenman 2007). This combination of factors subjects public transportation to discussions of equity. Building service within localized areas, as opposed to aligning all service to the central business district, is part of

Social Equity: One of Many Goals

Social equity competes with other goals, including efficiency, economy, and the environment, in the planning and provision of transit service (Radbone 1994). While Le Grand (1991) disputes that decisions inherently involve trade-offs between equity and efficiency, the practical reality is that providing service to low-ridership areas in the pursuit of social equity will at the very least not result in the largest potential gains to overall accessibility. Drawing on an extensive literature review, Jones and Lucas (2012) state transport investments typically focus on economic growth and CO₂ reduction; the social equity dimension is largely ignored. Likewise, neither changes to accessibility nor their distribution among various groups are commonly considered in ex ante evaluations (van Wee and Geurs 2011), likely due in part to the difficulty of measurement (Radbone 1994).

Radbone's (1994) prescription for increasing transit equity. An additional complication arises when attempting to balance the need for local service in high-ridership areas against the preferences of suburban residents who tend to favor commuter lines (and rail). The support of suburban residents may be necessary to gain political and financial support for the system as a whole (Garrett and Taylor 1999). The Los Angeles Bus Riders Union's suit against that city's metro system punctuated this issue: the union argued that too many resources were being spent on rail development to suburban areas and won legally-binding concessions for investments in bus service (Grengs 2002).

Equity implications also arise from how different groups use the system. For instance, short trips typically subsidize longer trips, especially when the fare structure is flat. Given that inner-city low-income and minority populations typically make shorter trips than their suburban counterparts (Sanchez and Brenman 2007, 43), distance-based fares may serve to increase equity (while flat fares may detract from equity). However, location-specific analyses must be performed (Farber, et al. 2014, Radbone 1994) to draw conclusions about the equity of any particular city's or region's service.

Equity also depends on choice. Norman Krumholz (1982) is famous for casting equity planning as an effort to provide more choices to those who have few, if any, choices. Hay (1993) argues that equity depends on the maximization of choices available. Le Grand (2006) continues this line of thought, saying the poor and disadvantaged are less well placed than the better off to exercise choice effectively. Transit system policies therefore must aim to increase the choices (of services) available to transit users, while also assisting the least well-off with transport and travel costs (Le Grand 2006). A complicating factor is that some people choose to live in areas with low transit accessibility (van Wee and Geurs 2011). However, this may be partially

overcome by evaluating accessibility against income, as shown in Figure 2.

2.2.2 Measuring Transit Equity

Two broad conceptions of measuring equity in

transportation exist in the literature. The first analyzes the distribution of benefits and burdens among different groups (who gets, who pays). As stated previously, a complete evaluation of a system's equity must involve analyses of the distributions of benefits *and* burdens. Given the list in Table 2, a comprehensive analysis is a tall order and well beyond both this paper's scope and its author's capabilities. Furthermore, the target of this paper's analysis, Metro's Service Guidelines, is not explicitly concerned with who pays. This may be a shortcoming of the Guidelines, but I do not take on that argument here. The second conception of measuring equity involves some form of needs assessment of the people being analyzed and typically results in defining groups. It then compares the level of access or accessibility available to each group, focusing primarily on the distribution of benefits. This paper adopts the latter framework.

2.2.2.1 Who Matters?

Table 3 summarizes various characteristics used in studies and discussions of transportation and transit equity, some of which are debated in the literature (Foth, Manaugh and El-Geneidy 2013). In general, when choosing which groups to include in an analysis, some form of qualitative needs assessment is conducted; though this approach is relatively practical, it is not universally accepted (Martens, Golub and Robinson 2012).⁷ These assessments are inherently subjective,

Figure 2. Degree-of-Concern Matrix

	Low accessibility	High accessibility
Low income	Highest concern	Little to moderate concern
High income	Little concern	Least concern

⁷ Recall that these authors find it problematic to define how much need any given group may have. Instead, transit service should seek to meet the floor requirement as defined by the maximum acceptable range in access levels (which is anchored to the maximum access provided by the entire transportation system).

but they are largely based on common sense. Table 4 lists reasons for each group's inclusion in analyses. Given the selections available, the choice of groupings should reflect the information sought (Foth, Manaugh and El-Geneidy 2013); for instance, if one seeks to understand how accessibility changes with income, defining groups based on income would be appropriate. However, this simplistic approach is more reasonable for discrete investigations than it is for holistic planning. Some other guiding principle is required.

Murray and Davis (2001) define who matters in terms of both need and access. "Transport disadvantaged groups" are those who need transit but who cannot access it (580-1). Thus, those who have no vehicle, no or poor access to transit, or are disabled (no or low personal mobility) should be the focus of analysis. This framework is helpful in identifying gaps in service, but it does not help in determining the equity of relative levels of accessibility among groups who *already have* some accessibility via transit.

Many of the factors in Tables 3 and 4 likely have high degrees of collinearity, and most only indicate a *potential* need for transit service. As a minimum, those who cannot use automobiles need transit (excluding the possibility of walking, biking, taxis, and ridesharing); this includes the disabled and people too young to legally drive. The elderly may sometimes fit this category, but research indicates many older people continue to drive (Foley, et al. 2002). Drawing on transit's role in the rectification of historical (and potentially current) injustice, racial and ethnic minorities can also be included. Finally, those with low-incomes fit squarely within Rawls' least advantaged members of society, and it is clear that, all things being equal, the poor will have a more difficult time accessing the auto-based transportation network than the more well-off (Welch 2013, Johnson, Currie and Stanley 2010).

Table 3. Factors Used in Social Equity Analysis

Author or Source	Income	Housing cost	Household Structure	Race/ethnicity	Gender	Car ownership	Employment status	Educational attainment	Receipt of State Benefits	Immigration status	Low English proficiency	Disabled	Elderly	Youth	Native Americans	Density/distance from CBD	Internet access
Sanchez and Brenman (2007)	x			x							x	x	x		x		
Currie (2004)	x					x	x					x	x	x		x	
Currie, et al. (2009)	x					x											
Australian Bureau of Statistics	x	x				x	x	x				x					x
Litman (2014)	x					x											
Grengs (2015)	x			x													
Garrett and Taylor (1999)												x	x	x			
Farber, et al. (2014)	x			x				x					x	x			
Foth, Manaugh and El-Geneidy (2013)†	x	x					x			x							
Popoks (2014)	x						x						x	x			
Murray and Davis (2001)	x					x					x	x	x	x			
Morris (1981)	x						x			x		x	x	x			
Starrs and Perrins (1989)	x			x	x							x	x	x			
Manaugh and El-Geneidy (2012)	x							x		x							
Wells and Thill (2012)	x			x									x	x			
Biggins McMullen (1994)	x						x						x	x			
Ircha and Gallagher (1985)	x											x	x	x			
Martinelli and Medellin (2007)	x			x	x								x	x			
Mamun and Lownes (2011)	x					x						x	x				
Tribby (2009)	x												x	x			

†Focused on jobs access

Table 4. Groups/Factors and Justification

Group/Factor	Justification
Low-income	Less able to afford automobiles
Housing cost	Less able to afford transportation
Household structure	Potential social disadvantage, e.g. single mothers
Race/ethnicity	Historical/current injustice
Gender	Women more likely to travel off-peak, have part-time jobs
Car ownership	Dependent on transit or choose transit
Employment status	Social disadvantage
Educational attainment	Social disadvantage
Receipt of state benefits	Indicator of low-income and/or social disadvantage
Immigration status	Potential social disadvantage, low English proficiency
Low English proficiency	Barrier to access
Disabled	Unable to drive
Elderly	Unable or unwilling to drive
Youth	Unable to drive (legal limitation)
Native Americans	Historical/current injustice
Density/distance from CBD	Locational disadvantage; locational choice disadvantage
Internet access	Need for more transportation, as tasks cannot be accomplished at home

Sources: Currie (2004); Sanchez and Brenman (2007); Australian Bureau of Statistics (2013); Litman (2014); Grengs (2015); Garrett and Taylor (1999); Farber, et al. (2014); Foth, Manaugh and El-Geneidy (2013); Popoks (2014); Murray and Davis (2001); Morris (1981); Starrs and Perrins (1989); Manaugh and El-Geneidy (2012); Wells and Thill (2012); Biggins McMullen (1994); Ircha and Gallagher (1985); Martinelli and Medellin (2007); Mamun and Lownes (2011)

Car ownership, though, remains a sticky issue in the literature. It is a poor proxy for household deprivation (Townsend, Phillimore and Beattie 1988). Some people choose to not own a car (similar in nature to some people choosing to live in areas of low accessibility). If it is used as a criterion, it should be combined with another factor, such as low-income; this would have the effect of excluding the “choice carless” from the group. Mamun and Lownes (2011) and Currie, et al. (2009) used the reverse of this technique in applying the concept of “forced car ownership” to their studies. When sufficient transit access is unavailable, the poor are forced to own and operate cars and are therefore forced to spend a larger proportion of their household budgets on transportation; this contributes to the inequity of the transportation system. In this sense, low-

income households *with* cars can be double-counted; not only are they on the lower end of the income spectrum, but they are *forced* to pay proportionally more for an equivalent level of transport accessibility.

2.2.2.2 *Access and Accessibility*

Access and accessibility are the most appropriate measure of the benefits of transportation plans and investments (Martens and Golub 2014). These two terms, though similar, describe different things. Access is concerned with the ability to use the transit system. Most often, this is measured in terms of distance to transit access points (stops and stations) (Murray and Davis 2001). Though there is no consensus, accessibility is generally considered as the ease with which someone can get from one place to another (van Wee and Geurs 2011, Bocarejo and Oviedo 2012, Murray and Wu 2003); some call this mobility (Martens, Golub and Robinson 2012). Access precedes accessibility; without access, there can be no accessibility. However, when access is present, accessibility may range from low to high, depending on four factors: the spatial distribution of activities (land use); the transport system; a temporal component (when are opportunities available, and how much time do people have); and individual needs and abilities (van Wee and Geurs 2011).

In terms of the equity of accessibility, and drawing on the idea of a minimum floor, it is not only the distribution that must be examined, but the absolute level of accessibility as well (van Wee and Geurs 2011).⁸ Basic accessibility implies that “people can obtain goods, services and activities that are considered valuable to society, such as emergency services, medical care, education, employment, food and clothing” (van Wee and Geurs 2011, 354); this is “equity of

⁸ This discussion stands in opposition to the maximax principle chosen by Martens, Golub and Robinson (2012).

opportunity,” a form of vertical equity that strongly relates to Tomasi’s belief that extreme need (or when applied to this argument, extreme lack of accessibility) can threaten the ability of people to exercise their moral power of self-authorship. Van Wee and Geurs (2011) think basic accessibility to some destinations can be a Rawlsian primary social good. Litman (2014) calls “basic mobility” a merit good; trips to services with positive externalities (education, employment, basic services) are normally thought to need support, whereas “luxury” trips should be self-supported.

The concept of accessibility begs the questions *from where?* and *to where?* In short, *what matters?* While it may be attractive to think that a person’s having greater overall accessibility (to things) will result in better outcomes, it may not necessarily be true (van Wee and Geurs 2011). Matching people and the destinations they wish to reach is necessary. With a gridded road network and private automobiles, relatively little thought must be paid to which places are connected to which people: access to the grid yields the maximum possible accessibility. Transit networks differ; buses and trains cannot run on every road, and resource-constrained environments dictate that only some places and people be connected. It is probably safe to assume – as a basic starting point – that the poor will need to access lower-wage jobs and social services, that students will need to access schools, that retired people may not need to access jobs, but may have greater need to access health care, and so on (van Wee and Geurs 2011). One final thought: making accessibility matter, which bears a resemblance to substantive equity, requires generous public access to planning processes to ensure that the places people *can* reach are the places people *need* and *want* to reach.

2.2.2.3 Methodologies

Having discussed people of concern, access, and accessibility, I turn now to their measurement.

Methodologies for measuring equity can be divided into three separate parts: measuring people, measuring access/accessibility, and then, measuring equity.

Two methods exist to account for differences among people. The first simply involves dividing a population into two or more groups based on a chosen criteria. Many of the studies mentioned thus far use income, either in a binary (low-income or not-low-income) or a stratified fashion.

Race and ethnicity are similarly used, often separating Whites from all non-Whites.

Comparisons between the groups are then made. The other method involves the creation of an index that combines multiple measures of disadvantage or need. Factors are standardized before assigning individual weights (or weighting all factors equally) (Currie 2004, Foth, Manaugh and El-Geneidy 2013, Manaugh and El-Geneidy 2012, Murray and Davis 2001). The standardization should result in each ‘level’ of each factor representing roughly the same amount of need (Murray and Davis 2001). Index values for each geographic zone (often transportation analysis zones (TAZ) or census geometries) are then calculated. Differences between “high disadvantage” and “low disadvantage” zones can then be identified; alternatively, a portion of the zones representing the most *compositely* disadvantaged can be used in the analysis (Manaugh and El-Geneidy 2012).

Methods for measuring access and accessibility are more varied and complex. Baradaran and Ramjerdi (2001) group various accessibility measures into five classes: travel cost (how easy it is to travel), gravity/opportunity (the potential to travel), constraints-based (taking into account what a person *can* do); utility-based surplus (perceptions of accessibility); and composites of the preceding four. Most methods rely on a mix of concrete aspects and abstractions of transit

networks; these (varyingly) take into account frequency, speed, capacity, transfers, comfort, and stops, often aggregated in various ways by geographic units (zones). Ultimately, they attempt to determine the *value* transit provides to a particular place. Value is defined in different ways: in terms of access (the ability to reach transit, also referred to as gap analysis) (Murray and Davis 2001, Currie 2004, Currie 2010); in terms of connectivity (how well the system allows users to move from one point to others) (Popoks 2014, Mamun, et al. 2013); in terms of share of service (Delbosc and Currie 2011, Levinson 2002, Martinelli and Medellin 2007, Welch 2013); and in terms of accessibility (including not only where people can get to, but the opportunities available at those destinations) (Grengs 2015, Bocarejo and Oviedo 2012, Owen and Levinson 2014, Manaugh and El-Geneidy 2012, Shen 1998).

In a review of literature, Popoks (2014) found four limitations in existing measures of connectivity: many are not network-based, travel time is deterministic (on-time performance/reliability is unaccounted for), and some do not account for comfort and discomfort. Finally, while some studies account for transfers (usually with a time penalty), they provide no representation of the additional inconvenience of each subsequent transfer in a single, linked trip. His complex method of determining connectivity corrects these deficiencies and is one of the most comprehensive and labor- and data-intensive methods in the literature. The last two of his cited limitations (comfort/discomfort and transfer inconvenience) depend on personal preferences; Wells and Thill (2012)⁹ also indicate customers care most about comfort/convenience (including safety, travel time, and reliability) in addition to availability (spatially and temporally). However, Martens and Golub (2011) argue that when comparing

⁹ Citing a 2003 study by Kittelson and Associates.

individuals from an equity perspective, that which is within the realm of the *possible* is what counts; preferences may only need to be a secondary consideration.

In contrast to more complex methods, a simpler and more straightforward starting point lies in Hansen's (1959) classic cumulative opportunity measure:

$$A_i = \sum_j O_j f(C_{ij})$$

A_i = accessibility for location i

O_j = number of opportunities at location j

C_{ij} = time cost of travel from i to j

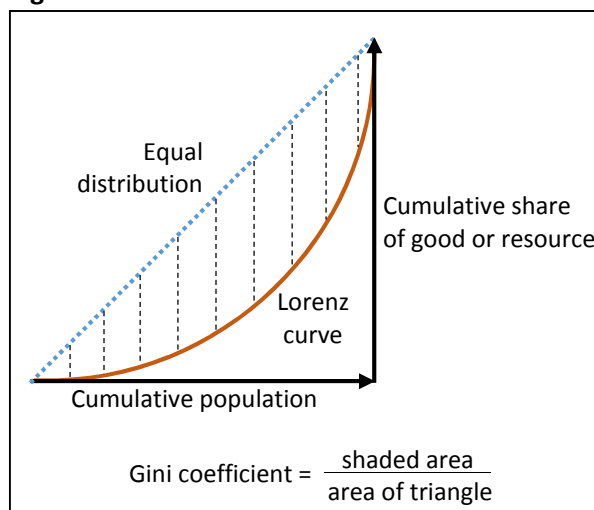
$f(C_{ij})$ = weighting function

Opportunities are typically represented as jobs, and weighting functions can be determined based on empirical evidence gathered from the study area. Shen (1998) introduced the conception of demand-weighted access to opportunity to take into account the rival nature of jobs. While jobs are certainly rival, I argue that *opportunities* to get jobs are *nonrival*; anyone can apply to any job opening. Of course, individuals' chances of being hired will vary based on skills and background, which brings to light that in determining access to opportunities, it is important to match people with "appropriate" opportunities (Manaugh and El-Geneidy 2012, Harris 2001, Shen 1998). For example, a measure of the access a low-education, low-income person has to executive or high-tech jobs would not be very useful and would mask spatial disadvantage.

Measuring equity involves combining a measurement of people with a measurement of access or accessibility. In planning, a single, quantitative value of the change in equity for each planning alternative under consideration may be necessary to enable decision-making (Murray and Davis

2001). One method that accomplishes this involves the use of Lorenz curves and Gini coefficients to assess the equity of the distribution of transit service. Lorenz curves visually depict the deviation of a particular distribution from a perfectly equal (differing from “equitable”) distribution; the cumulative population is typically plotted on the x-axis,

Figure 3. The Lorenz curve and Gini coefficient



while the cumulative share of whatever is being measured is plotted on the y-axis (Figure 3).

The Gini coefficient is the ratio of the total area under the equal distribution line to the area between the equal distribution line and the line representing the distribution in question. A ratio of 1:1 (where the Lorenz curve is the same as the equal distribution line) represents perfect equality, while a ratio of 0:1 represents perfect inequality (only one person has all shares). Delbos and Currie (2011) demonstrated this technique in a study of Melbourne, but they confused equality with equity. They found that 70% of the population shared only 19% of the supply of public transit (Gini coefficient of .68), but a Gini coefficient of > 0 indicates a distribution is *unequal*, not necessarily that it is *inequitable* or *unfair*. Levinson (2002) likewise blurred the line between equity and equality in claiming that the change in the Gini coefficient before and after a project gives some sense of whether a project is “equity enhancing or equity subtracting” (enhances fairness or subtracts from fairness). A generalized example of the distribution of food assistance (e.g. food stamps) proves the counterpoint: a very small proportion of the population receives the majority of assistance; we would hardly think it *equitable* if food stamps were distributed *equally* among all members of society (Gini coefficient

of 0). Another limitation of this method is that it depends on the ability to quantify a discrete total of a good. The authors above use various measures of transit *supply* (for example, the total number of transit trips serving a zone in a week). This paper, though, focuses on transit *accessibility*, which does not have a discrete “total.” The amount of accessibility one person enjoys can be enjoyed by others, often at the same time and in virtually the same space; in other words, one person’s share does not diminish another’s share to the same extent as when measuring shares of wealth or income. (If you have one dollar, I cannot simultaneously have the same dollar.)

The cumulative opportunity measure presented earlier is used throughout the literature in various forms, and it can be aggregated to produce a single “score” for a study area (Owen and Levinson 2014); this score can then be compared to the scores of other areas. However, measuring equity does not require all data to be boiled down to a single value, and doing so obscures spatial variations in accessibility. Comparisons by degree of disadvantage (Foth, Manaugh and El-Geneidy 2013, Currie 2004), zonal percentiles (of, e.g., low-income or minority) (Grengs 2015), or zone-by-zone comparisons (for example, Popoks (2014)) can preserve the detail required to assess spatial and need-based disparities.

I feel the need to remind readers of two points. First, none of these methods analyze the distribution of both benefits *and* burdens, which, as previously established, is necessary to gain a full picture of a system’s equity. Second, this paper similarly only evaluates the distribution of benefits and thus provides only *half* of the picture.

2.2.3 Laws and Policies

While so much debate about the philosophical and theoretical underpinnings of equity continues, the United States is a republic of laws. The rule of law establishes the baseline requirements that must be followed. All else is subject to personal opinion. The previous sections have at least hinted at normative notions; in contrast, this section strikes a positive tone. It describes the various laws and policies relating to equity and justice that King County Metro, this paper's target, must follow.

- **Title VI of The Civil Rights Act of 1964.**¹⁰ This law prohibits discrimination by recipients of federal aid on the basis of race, color, religion, sex, or national origin. All programs run by the recipient, even if not directly federally funded, are subject to this law. Federal court cases have effectively stripped the ability of individuals and advocacy groups to file suit, as proof of intentional discrimination is required. However, this does not lift the requirement for agencies to comply with the law and its implementing regulations¹¹ (Sanchez and Brenman 2007).
- **Americans with Disabilities Act (ADA) of 1990.**¹² This law bars discrimination based on disability; individuals with disabilities may not be denied the benefit from a service based on their disability. In terms of transit, the service afforded to persons with disabilities must be equal to that afforded to others. Equivalent alternatives may be developed with public participation and approval from the Federal Transit

¹⁰ 42 U.S.C. § 2000d et seq.

¹¹ See 28 C.F.R. § 42.401 et seq.

¹² Pub. L. No. 101-336, 101st Congress, July 26, 1990; Pub. L. No. 110-325, 110th Congress, September 25, 2008; 42 U.S.C. Ch. 126.

Administration. A paratransit service comparable to fixed-route service is also required for those who cannot otherwise use a system's service.

- **Executive Order 12898.** This order, Federal Actions to Address Environmental Justice in Minority Populations and Low-income Populations, effectively extends Title VI protections to low-income populations. It is implemented for agencies receiving federal assistance by US Department of Transportation Order 5610.2(a) and Federal Highway Administration Order 6640.23A. Regulations include steps to prevent disproportionately high and adverse effects of programs and policies on protected populations. What constitutes “disproportionate” is not defined and is left to agency discretion (and perhaps that of the community, via a public process). The order also does not explicitly prohibit disproportionate effects; as such, it does not create enforceable legal rights (Cambridge Systematics 2002). It also focuses solely on the distribution of *adverse* impacts. Lastly, the order requires the implementation of procedures to provide meaningful opportunities for public involvement in planning and project development.

- **Executive Order 13166.** This order, Improving Access to Services for Persons with Limited English Proficiency, aims to extend Title VI protections to limited English proficiency (LEP) populations by relating this factor to national origin. It directs agencies to identify need for services among LEP populations and develop systems to give them meaningful access.

- **National Environmental Policy Act of 1969¹³ and Washington State Environmental Policy Act.**¹⁴ These laws require an assessment of a program’s or project’s environmental effects, including human health, economic, and social effects on minorities, low-income populations, and Indian tribes.

- **Puget Sound Regional Council (PSRC) Transportation 2040 and the Washington State Growth Management Act (GMA).**¹⁵ While the PSRC’s policy document does not contain any mandates for King County, the GMA requires county plans to be consistent with regional plans. Transportation 2040 incorporates equity considerations based on federal and state requirements (Puget Sound Regional Council 2010). As long as local programs and policies remain consistent with Transportation 2040, they will inherit the equity issues already considered in the development of the regional plan.

- **King County Ordinance 16948.** This law implements the “fair and just” principle of the county’s strategic plan. It states that “‘equity’ means all people have full and equal access to opportunities that enable them to attain their full potential” (3) and that “‘inequity’ means differences in well-being that disadvantage one individual or group in favor of another” (5). The ordinance directs the executive branch to advance equity in all departmental policies and programs. It also defines 14 determinants of equity; the one most applicable to the present discussion is “Transportation that provides everyone

¹³ Pub. L. 91-190, 42 U.S.C. 4321-4347, January 1, 1970, as amended by Pub. L. 94-52, July 3, 1975, Pub. L. 94-83, August 9, 1975, and Pub. L. 97-258, § 4(b), Sept. 13, 1982.

¹⁴ RCW 43.21C.

¹⁵ RCW 63.70A.

with safe, efficient, affordable, convenient and reliable mobility options including public transit, walking, car pooling, and biking” (3).

- **King County Executive Order ACO 9-2 (September 2014).** This order, Advancing Equity and Social Justice through Development of a Strategic Innovation Priority Plan and Executive Department Actions, directs departments to take actions to advance equity in the county. Establishing in-house training and awareness programs, increasing LEP populations’ access to services, and aligning budgets to the determinants of equity are specifically directed.
- **King County Metro Strategic Plan for Public Transportation and Service Guidelines.** This policy document (adopted by King County Council Ordinance 17386) aims to advance equity in a number of ways. The transit system’s design should “support social equity and environmental justice by providing mobility options to those who have no or limited transportation options” (11). The Service Guidelines are contained in the plan and are discussed in detail in the next section. They include the consideration of social equity in the allocation of fixed-route transit service. Balancing productivity, social equity, and geographic value is explicitly addressed by the Strategic Plan (Goal 6: Financial Stewardship) (31). Additionally, Strategy 7.1.1 of Goal 7: Public Engagement and Transparency calls for building capacity to include the public in planning processes, and Strategy 7.2.1 establishes policy to increase access for LEP populations (37), consistent with federal and local mandates.

In general, federal laws require the consideration of far fewer factors relating to equity than are represented in the literature. Low-income, minority (including race, color, and national origin),

and LEP populations are the only “classes” that must specifically be accounted for.

Additionally, local laws and policies do not explicitly add any groups to those that must be legally considered in programs and planning under federal law. They are, however, flexible and do not explicitly *exclude* the consideration of other groups that may be determined to be in need. For example, “those who have no or limited transportation options” (King County Metro 2013a) is a broad category, and Metro could consider many of the groups used in the literature and remain consistent with laws and policies. Beyond federal requirements, Metro is therefore empowered to choose which groups to specifically consider, both in terms of inclusionary planning and in evaluating equity.

Guidance and legal requirements for action vary at the federal and local levels. Title VI explicitly bars discrimination, while EO 12898 and its implementing regulations merely require the consideration of adverse impacts when planning. EO 13166 *advises* agencies to increase LEP access to services to avoid suits under Title VI. In King County Ordinance 16948, we can see an instance of the line between equity and equality being blurred, as “equity” is defined as “equal access to opportunities.” In terms of transit’s role in providing access to opportunity, the ordinance establishes a practically unachievable goal: equality of accessibility. This is due to the fundamental nature of the transportation system as auto-centric, as previously discussed. Until such time as the transportation system, as a fundamental characteristic of its design, does not provide the highest level of accessibility to automobiles, Metro is essentially forced to adopt a practical interpretation of the ordinance’s mandate: to increase access to opportunity to the greatest extent possible, given real-world resource constraints. Alternatively, it could adopt a radical policy of subsidizing private auto purchases, which has been suggested in the literature (Grengs 2010), but which is in all likelihood politically infeasible.

2.3 Equity in Practice: King County Metro

This section continues to narrow the focus by examining the practices of Metro, where the rubber of social equity theory and philosophy hits the actual road. Metro addresses equity robustly across the entire organization (King County Metro 2013b) and uses the county's Equity Impact Review (King County 2010) for major programs and projects. The present discussion focuses on the equity of accessibility, and three categories will be discussed: service planning, ADA compliance and LEP, and service evaluation.

2.3.1 Service Planning

The ways in which service planners incorporate social equity into practice fall into four broad categories: using outputs from the Service Guidelines analysis, less formal accounting of social equity impacts of service changes, engaging with the community, and conducting Title VI analyses. The Service Guidelines explicitly incorporate social equity factors into the determination of where investments and reductions should be made; service planners retain the responsibility to translate those investments and reductions into changes in actual service. The inclusion of social equity is therefore included in their planning efforts by the transitive property. However, Metro planners do not rely exclusively on the outputs of the Service Guidelines analysis when planning changes in service. Additional information on the locations of social services, schools, and populations in need is taken into consideration, but this process is less formal and relies on institutional knowledge and available data (Fichter and Arai 2015). Lastly, and perhaps representing the most robust effort, service planners conduct extensive public engagement activities when planning major service revisions. This process is both iterative and proactive, with Metro proposing changes and soliciting feedback multiple times from as diverse a group of stakeholders as is feasible within resource constraints (Fichter and Arai 2015). The

process meets or exceeds requirements for public participation set forth in the ADA, EO 12898, and FTA guidance, is consistent with prevailing notions of the importance of public involvement in planning as reflected in literature (Levinson 2002, Federal Transit Administration 1995, Beatley 1988), and advances Metro's Strategic Plan Goal 7: Public Engagement and Transparency (King County Metro 2013a). The service planning function also incorporates requirements of Title VI; these are discussed below as part of Section 2.3.4: Measuring Equity.

2.3.2 ADA Compliance and LEP

Metro complies with all aspects of the ADA. All Metro buses are accessible to persons with disabilities, as defined by the law, but not all stops and stations are (King County Metro n.d.). Customers can become paratransit-eligible if their needs are not met by existing infrastructure. Metro's Access Transportation program is its ADA-compliant paratransit service, offering next-day rides anywhere Metro bus and Sound Transit bus and rail services operate. Metro also participates in a regional reduced fare permit program that provides disabled persons a discount of between 66% and 75% (King County Metro n.d.).

Metro in 2012 developed a plan to improve access to services among people with limited English proficiency (LEP), following FTA guidance and specifically responding to EO 13166 and its implications for Title VI compliance (King County Metro 2012a). Overall, the plan is designed to increase the ability of LEP populations to access Metro's services. To accomplish this goal, Metro prints a limited amount of materials in foreign languages, primarily Spanish, and provides translation services for other commonly-spoken languages in the county. Several brochures containing instructions on riding the bus are available in multiple languages and distributed throughout non-English speaking communities. Outreach to community groups and

reassessments of needs are routinely accomplished, consistent with Metro’s Strategic Plan (King County Metro 2013a).

2.3.3 Service Evaluation (Service Guidelines)

Metro’s method of evaluating service and determining how to allocate it throughout the county is contained within the Service Guidelines (King County Metro 2013a). The Guidelines resulted from the Regional Transit Task Force in 2010, a months-long stakeholder participation process that produced recommendations to guide service allocations, including the following for social equity:

[The task force] defined Social Equity and Environmental Justice to mean using transit service to address gaps in mobility, and to avoid or mitigate disproportionately high and adverse social, economic or human health impacts for populations that have limited transportation options, including youth, students, elderly, disabled, people of color, those with limited English proficiency, and economically disadvantaged communities. (Regional Transit Task Force 2010)

As part of implementing the Guidelines, Metro established service corridors, largely reflecting the service in place at the time. Corridors are designed to connect places, and multiple routes or parts thereof may serve multiple corridors. Social equity is explicitly taken into account as part of an annual analysis of these corridors, specifically taking into consideration low-income and minority populations. The corridor analysis uses a two-step process to determine how much service each corridor *should* have (Figure 4). The first step balances land use, social equity, and geographic value to generate a composite score that sets an “initial service level” for each corridor:

- Land Use (50% of the score): based on the number of households and jobs within ¼-mile, network-based walksheds of stops contained within the corridor;
- Social Equity (25% of the score): based on the proportion of boardings occurring within low-income and minority census tracts (12.5% each); and

as candidates for investment. Investments are prioritized by four categories; failing to meet target service levels qualifies a route for investment priority three (see Figure 5).

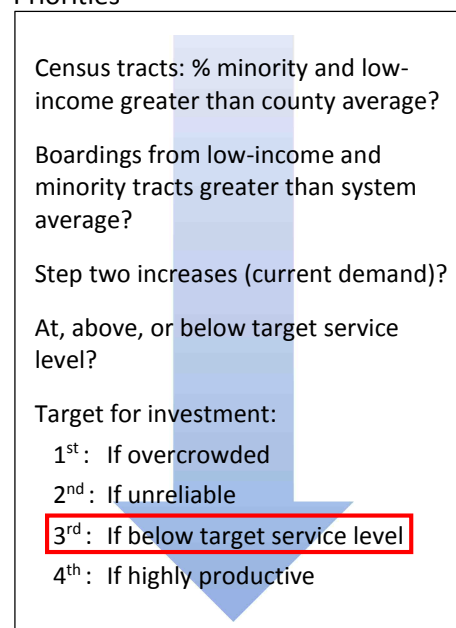
2.3.4 Measuring Equity

The measurement and tracking of equity at Metro, at least in the latest conception thereof as established in the “fair and just” ordinance, is in a fledgling state. The 2015 King County Determinants of Equity Report represents the first concerted effort to choose metrics that may help determine the equity of policies and programs throughout the county. The report established preliminary measures in an attempt to capture the aspects of county government functions that impact equity. For

the transportation determinant, metrics measuring the safety, efficiency, convenience, reliability, and affordability of transit are included. The report acknowledged limitations of available data and the resulting difficulty in providing a comprehensive picture of equity. Also, the report did not attempt to measure the equity of the *entire* transportation system, but instead focused on the transit Metro supplies. Of particular applicability to the present discussion is the report’s inclusion of access to transit. This indicator aligns with Metro’s Strategic Plan and measures the proportions of low-income, minority, and total population within either a ¼-mile of a transit stop or two miles from a park-and-ride, reported collectively and separately (King County 2015). No other metric of accessibility is used.

Metro’s compliance with Title VI mandates and FTA regulations can also be conceived of as a manner of measuring equity. When major service changes are planned, Metro conducts analyses

Figure 5. Social Equity in Investment Priorities



to fulfill Title VI requirements. “Major service change” is defined as: any single change or cumulative changes in a service schedule which affect weekly service hours for a route by more than 25%; or movement of a stop by one-half mile or more. The Title VI analysis determines whether minority populations are *disparately impacted* by adverse effects of a service change and whether low-income populations are *disproportionately burdened* by adverse effects. Metro defines “adverse effect” as a reduction of 25% or more of the trips serving a census tract or a reduction of 25% or more of the service hours on a route. Disparate impacts and disproportionate burdens are determined to exist if the share of adverse impacts on minority and non-minority populations and on low-income and non-low income populations, respectively, differ by more than 10% (King County Metro 2013a). The analysis complies with relevant laws and is consistent with FTA guidance (Federal Transit Administration 2012).

A Note on Public Servants and Advocacy

Compliance with the law is the minimum acceptable standard for workers in a government bureaucracy. Drawing on the Minnowbrook conferences that ushered in an era of social equity in public administration, Frederickson (2010) argues that policy advocacy on the part of the public servant is essential, and that social equity should be one of these policies; public administration should seek to influence, among members of society, the development of the norms it espouses. This is advocacy taken to the extreme: “to be an informed an expert voice for fairness and equity in the processes of policy formulation...is part of the public administrator’s job description” (Frederickson 2010, 137). This paper does not seek to discuss in full the merits or demerits of these ideas, but the belief systems of each public servant certainly plays a role in what he or she should advocate (assuming advocacy should even be a part of their duties), and we cannot expect everyone to hold the same beliefs and values.

3 Methodology

3.1 Research Questions

This paper seeks to answer the following questions:

- How should social equity be incorporated into the corridor analysis of Metro’s Service Guidelines and the resulting determinations of investments?
- Equity of the system: Based on a snapshot in time, to what degree does access to opportunity via transit vary by location and by relative disadvantage within King County?
- Equity of a change in the system: To what degree did a network change affect access to opportunity among varyingly disadvantaged groups, and how can these changes be evaluated in equity terms?

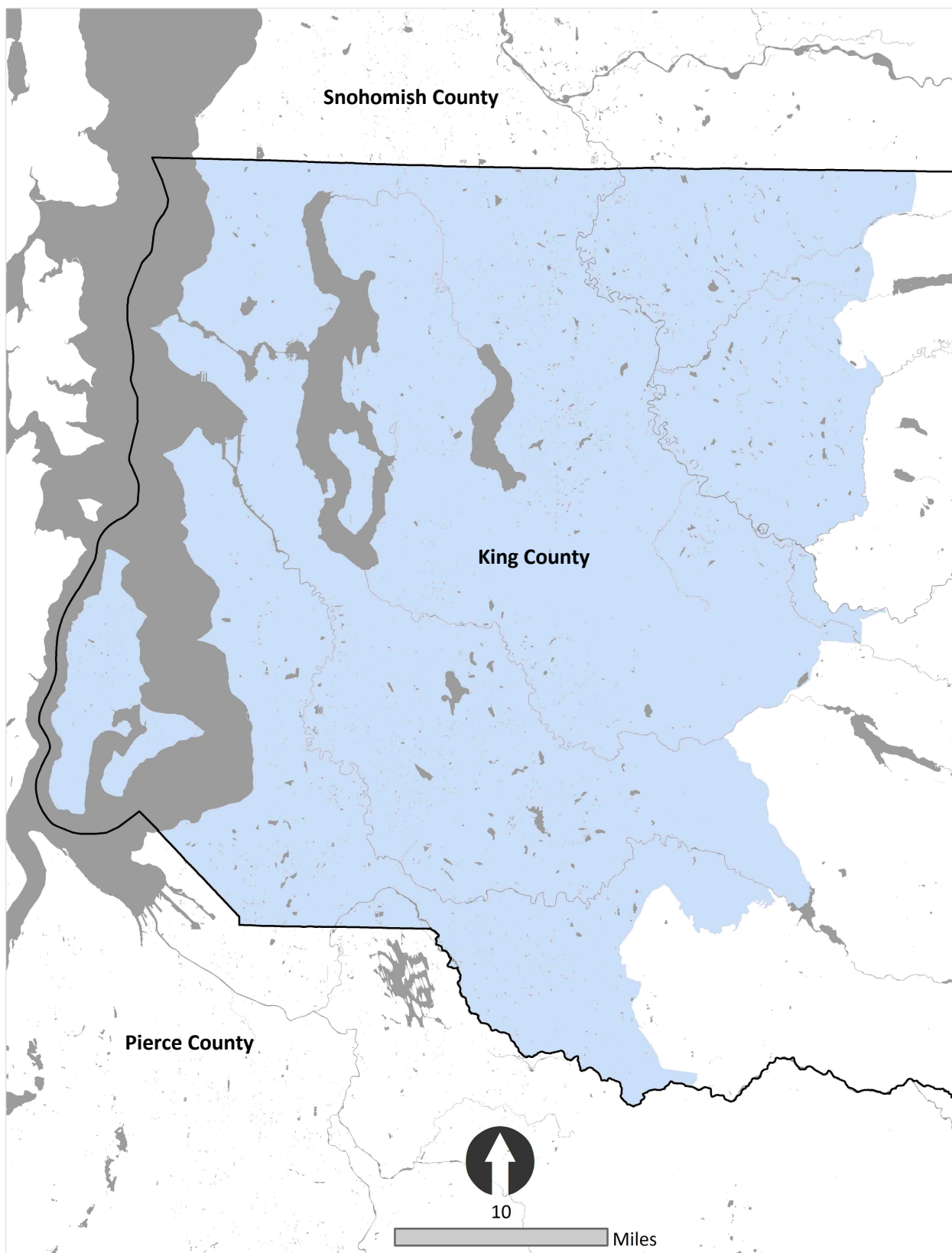
The first question implies a constraint: the corridor analysis framework contained within the Guidelines is taken as a given. While it is certainly possible to construct other frameworks whereby social equity could be incorporated into routine service allocation decisions, the framework within the Guidelines resulted from a significant amount of effort by Metro staff and members of the 2010 Regional Transit Task Force. My decision not to pursue an alternative framework was also guided by the scope of the Service Guidelines Task Force, a body formed in 2015 with the task of revising the Guidelines; this new task force is charged with tweaking the corridor analysis rather than conducting a complete overhaul.

3.2 Study Area

Nearly the entirety of King County, Washington composes the initial study area, as this is Metro’s service area (Figure 6). Four census block groups in the eastern portion of the county were excluded to reduce data processing and storage demands; additionally, transit service does not exist in these areas.

Two features of the data sets used in the methodology make the study area boundary marginally less rigid. First, Metro’s service extends slightly into Snohomish and Pierce counties to provide

Figure 6. Initial Study Area



better regional connections. The service provided to these areas is considered in the analysis, but no measurements are made of residents in other counties or the access or accessibility they experience. Second, in the accessibility analysis, destinations that can be reached in King, Snohomish, and Pierce counties are incorporated into the analysis to provide a more accurate picture of accessibility for those residents living on the northern and southern fringes of King County.

In addition to a system-wide snapshot in time, an additional analysis is conducted on a smaller study area to illustrate the methodology's use in revealing changes in accessibility when a network change occurs. A discussion of the criteria used to select this sub-area will follow the methodology sections below.

The following sections proceed in step-wise fashion by measuring people, measuring accessibility, and measuring equity.

3.3 Measuring People

3.3.1 Groups Under Consideration

Metro includes all federally-required considerations concerning equity in the provision of service and in service planning. However, this paper is examining the Service Guidelines, the primary policy document that dictates how Metro is to allocate service on a routine basis; this document explicitly includes only minority and low-income populations, leaving out LEP and disabled groups. Regarding LEP populations, the principal consideration is whether being unable to speak English well increases a person's need for transportation. I posit it does not, but LEP can factor into a broader definition of social disadvantage (Sanchez and Brenman 2007, Murray and Davis 2001). Providing more transit service to LEP populations *could*, therefore, be justified,

but my interpretation is that principles of justice do not necessarily demand it. Thus, there is no requirement to explicitly consider LEP populations in the corridor analysis. Instead, Metro should work to ensure LEP populations can meaningfully access the service that exists, and it is clear Metro is doing so (King County Metro 2013a, 2013b).

Regarding the disabled, the same consideration applies: does being disabled increase the need for transportation? Again, the answer is generally “no,” but it does increase the need for *certain means* of transportation, specifically, the ones Metro provides. Ensuring Metro services reach these populations is crucial if the agency seeks to increase social equity. Since fixed-route service is intended to be the “primary mode of public transportation for persons with disabilities,” (King County Metro n.d.), and since the Service Guidelines allocate fixed-route service, it follows that disabled populations should be explicitly included in the Guidelines framework. This is true even given the existence of Access paratransit.

As previously indicated, the inclusion of other potentially socially disadvantaged groups is not required by law, and choosing additional groups to consider would be subject to opinionated debate (the roots of which lie in the ongoing philosophical and theoretical debates about equity). Metro’s current practice largely reflects legal requirements, and this paper adopts the same approach. However, King County laws and policies do not prohibit the consideration of other factors; they may be included in future analyses should executives or the public deem their consideration worthwhile.

3.3.2 Disadvantage Index

The Service Guidelines allocate points to corridors based on their underlying characteristics; the corridor score determines the amount of service the corridor, by policy, should have. As

mentioned in the previous section, social equity points are assigned in a binary fashion. If corridors exceed threshold values (system-wide or county-wide averages), they are designated as “minority” and/or “low-income” corridors and receive all five points available for each category (maximum of ten points); if they fall below the threshold, they receive no points. This effectively discounts many low-income and minority populations in the corridor scores. As an alternative, this methodology constructs a combined index of social disadvantage and need called the “Disadvantage Index” (hereafter DI). Following the argument presented in Section 2, the index accounts for income, race/ethnicity, and disability. “Low income” is defined as households below the federal poverty level, consistent with current Metro practice. “Minority” is defined as people other than Not Hispanic or Latino, White Alone, again consistent with current practice. “Disabled” is defined as any person with either one or a combination of the following difficulties: hearing, vision, cognitive, ambulatory, self-care, or independent living. Hearing difficulties cannot be separated from block group level data, which is aggregated into a single disability category. The use of disability data at the tract level is also problematic, as data is either aggregated, as at the block group level, or disaggregated into individual disabilities, which introduces the possibility of double-counting (one person may have multiple disabilities). Following the literature (Foth, Manaugh and El-Geneidy 2013, Manaugh and El-Geneidy 2012, Murray and Davis 2001), each factor is standardized before being weighted equally in the composite index. This avoids normative judgments about which factor matters more and offers a measure of *composite disadvantage*, following Manaugh and El-Geneidy (2012). This methodology uses data at the census block group level from the American Community Survey (ACS) 2009-2013 5-year averages. Standard deviations from the mean are used to standardize each factor on a scale from 0 to 100. In order to arrive at a reasonable distribution of scores,

minimum and maximum points are reached at $\pm 1.5\sigma$ from the mean, with a linear progression between these points (Figure 7 and Table 5); no more than 8% of block groups in any category receive the highest or lowest score (0 or 100 points).

Table 5. Factor Standardization

Factor	Min	Max	Mean	σ	Standardization equation
Minority	0	.951	.358	.209	$i_m = 159.24x - 7.08$
Low-income	0	.795	.115	.119	$i_l = 280.99x + 17.82$
Disabled	0	.724	.183	.102	$i_d = 326.78x - 9.80$

Source: U.S. Census Bureau, ACS 2009-2013 Tables B03002, B17021, and B22010.

Note: i_m = minority index factor; i_l = low-income index factor; i_d = disabled index factor

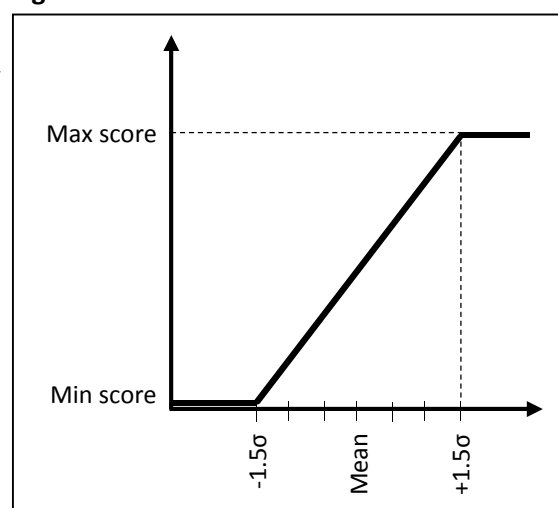
For each census block group, the standardized scores for all three factors are summed and divided by 30 to arrive at a 10-point scale consistent with the maximum social equity score allowed by the Service Guidelines.

3.3.3 Corridor Scoring

Each corridor's social equity score is determined using a GIS. Corridor geometries are overlaid on

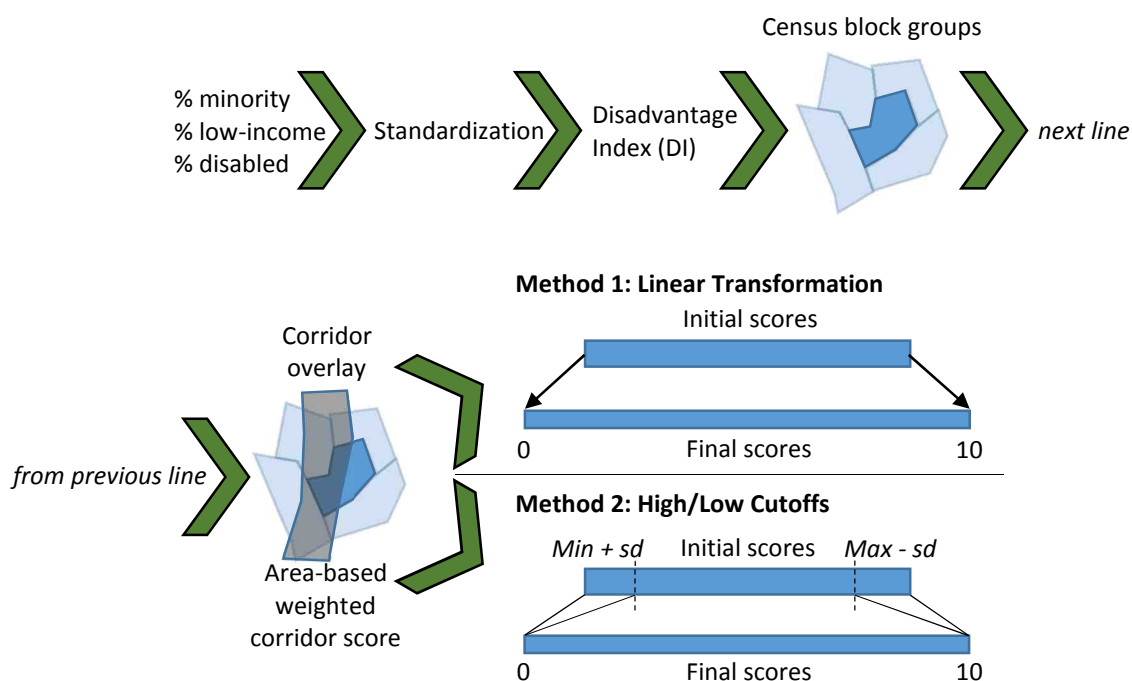
census block groups to produce an area-based weighted score, taking into account each underlying block group's DI value. This method assumes that minorities, low-income populations, and people with disabilities are spread evenly throughout each block group. It also gives equal weight to all areas within a given corridor. Section 5 contains a discussion of the benefits and limitations of this method and a comparison with the process contained within the Service Guidelines. The methodology presented here is used, in part, for comparative purposes and also because it is conceptually simpler in its approach.

Figure 7. Factor Standardization



Following the computation of each corridor's initial area-based weighted score, two separate methods are used to arrive at final values (for purposes of comparison). In Method 1, initial corridor scores are linearly transformed about the mean to attain a range of 0 to 10. The resulting values are then rounded to the nearest whole number. In Method 2, high and low cutoffs are established based on one standard deviation from the maximum and minimum initial corridor scores, respectively; initial scores below the lower cutoff are assigned a final score of 0, while initial scores above the higher cutoff are assigned a final score of 10. Scores in between the two cutoffs are scaled evenly from 0 to 10 (Figure 8).

Figure 8. Construction of the Disadvantage Index



3.4 Measuring Accessibility

The methodology used to determine accessibility combines aspects of work conducted by Grengs (2015), Owen and Levinson (2014), and Hardin (2013). It uses a three-step process:

- Step 1: Determine the possible areal extent of travel via transit (and walking) within a given time from a given location.
- Step 2: Determine which opportunities lie within this extent.
- Step 3: Weight opportunities based on travel time (friction), and sum them.

3.4.1 Determining Areal Extents

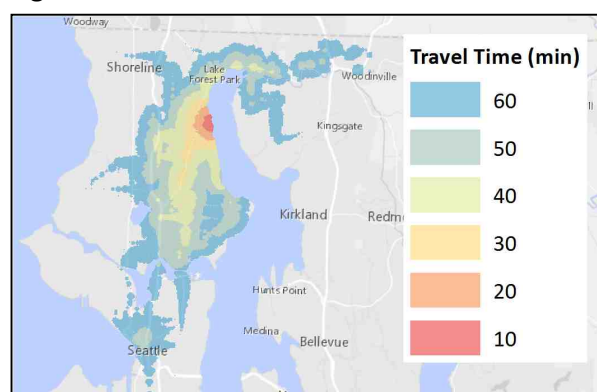
This methodology uses two set of inputs and one tool to construct “travel sheds” from each analysis zone. The first set of inputs consists of zone geometries. Zones are census block groups; their inner centroids are used as travel starting points (origins). The second set of inputs are published General Transit Feed Specifications (GTFS) from Metro and Sound Transit, both from spring 2014. These feeds provide all details about the transit networks: routes, stops, and timetables. The feeds from both agencies are used to give a more accurate and comprehensive picture of accessibility than if only Metro’s were used; this choice is also consistent with a recent initiative to better integrate the services of both agencies (Sound Transit and King County Metro 2014). The tool used to generate travel sheds was developed by Andrew Hardin and provided for use in this paper. A comparison of this tool to other methods and an explanation of its inner workings follow.

For their analysis, Manaugh and El-Geneidy (2012) defined origins and destinations as the transit stops closest to travel analysis zone centroids. This method produces higher levels of access than are actually experienced, as no measure of the cost of accessing transit is included. Popoks’ (2014) complex methodology uses the actual transportation network to determine the costs of door-to-door trips. In Hardin’s tool, travel times from designated starting points (in this application, census block group centroids) to transit access points are estimated by measuring the path density within grid cells. The cell size is customizable from within the tool; this application uses 100m² cells as a compromise between precision and data processing demands. Each cell’s

path density affects walking speed, with greater density equating to higher average speeds. Direct line travel from starting points to transit access points is used; to counterweight this underestimation of travel time, overall walking speeds are decreased within the model.

Following Owen and Levinson (2014), travel sheds are generated for six time thresholds, from 10 minutes to 60 minutes in 10-minute increments, from each of the 1,417 census block group centroids in King County.¹⁶ Figure 9 shows an illustrative set of these travel sheds.

Figure 9. Travel Shed Illustration



Although a single measurement in time could be used, travel times via transit are highly sensitive to the start time chosen (because transit does not depart on demand) (Owen and Levinson 2014). For this reason, a measurement is taken every minute for two hours in each of three time periods:

- 6:30-8:29 a.m., representing the morning peak period
- 11 a.m.-12:59 p.m., representing the midday period
- 3:30-5:29 p.m., representing the afternoon peak period

The two-hour windows ensure routes with headways of up to 120 minutes are captured. In total, over three million individual travel sheds are generated. Hardin's tool generates raster images, which are converted to polygons in a GIS to enable step two of the methodology (determining opportunities) to be completed.

One of the great benefits of this methodology is that *actual scheduled transit service* is used. No estimations or abstractions are necessary, and no extra accounting of transfer penalties need be

¹⁶ King County has 1,421 block groups. As previously discussed, four are excluded from the analysis.

accomplished. Additionally, the GTFS feeds are already published and publicly available. The methodology can be applied to the service area of any agency with a published GTFS feed.

Hardin's method is also beneficial in that he created a tool others can easily use; this is not the case with most other methodologies proposed in the literature. Researchers should take this into consideration if they desire to close the chasm between academia and practice.

3.4.2 Determining Opportunities

Opportunities are usually defined as jobs. Even when specific types of destinations are defined, the number of jobs at each destination can be used to weight their relative values. Grengs (2015) expanded the research into accessibility and equity by examining non-work access; the methodology in this paper follows suit, but it also measures jobs. Longitudinal Employer-Household Dynamics (LEHD) data provides jobs estimates at the census block level (centroid point data), with 2011 being the latest data available at the time this paper was drafted. In terms of defining other "opportunities," jobs are used as a proxy. North American Industry Classification System (NAICS) codes are used to differentiate between different types of opportunities, similar to Grengs' method. LEHD data with the desired level of spatial detail is available only at the 2-digit NAICS code level, which does not enable much specificity in the types of opportunities. In future applications, alternative datasets could be substituted in the methodology.

In addition to determining the total number of jobs falling within each travel shed, four additional "opportunity" categories are defined: retail and shopping (NAICS 44-45), education (NAICS 61), health care and social services (NAICS 62), and arts, entertainment, recreation, accommodation, and food services (NAICS 71-72). There are clear limitations to such broad definitions. For example, jobs in the online retail industry will appear in NAICS codes 44-45,

but these jobs do not represent shopping opportunities in the physical world. This limitation was chosen to avoid using more dated information from the U.S. Economic Census (2007) and the increased complexity in data processing that would arise from using jobs estimates conflated to ZIP code geometries.

To address questions of spatial mismatch and matching people with “appropriate” opportunities (Manaugh and El-Geneidy 2012, Harris 2001, Shen 1998), the number of jobs falling within each travel shed and associated with various educational attainment levels, as defined within the LEHD dataset, is also determined. These categories are:

- Less than high school
- High school or equivalent, no college
- Some college or Associate degree
- Bachelor’s degree or advanced degree

For ease of processing and presentation, the first two categories (hereafter “High School or Less”) and the last two categories (hereafter “Some College / College Degree”) are combined.

The jobs data is contained within a single dataset; the methodology requires only one spatial join for each travel shed.

3.4.3 Accessibility Scores

Following Owen and Levinson (2014) and Levinson and Kumar (1993), jobs farther away from each starting point will represent less “opportunity” than those closer in. A negative exponential impedance function is used to model this friction. Each block group’s accessibility value, for each of the three time periods, for each category of opportunity is:

$$a_{bc} = \frac{1}{n} \sum_{n,t} (j_t - j_{t-10}) \times e^{\beta t}$$

where a_{bc} is the accessibility of census block group b for category c , n is the collection of time indices for the period being measured (6:30, 6:31, etc.), t is the collection of time thresholds (10 minutes, 20 minutes, ..., 60 minutes), j is the number of jobs reachable (within 10 minutes, 20 minutes, etc.), and β is -0.08, following Levinson and Kumar (1993).

3.5 Comparing Accessibility I: Snapshot in Time

Section 3.3 established a Disadvantage Index (DI) for each census block group, and section 3.4 established various measures of access to opportunity (accessibility), likewise for each block group. This section describes the methodology used to derive meaningful information about the equity of a transit system based on a snapshot in time. The next section discusses methods to assess the equity of a *change* in the network.

As previously discussed, Gini coefficients can be used to measure the *equality* of transit *supply*, but they do little to tell us about the *equity* of the distribution of transit *accessibility*.

Furthermore, judgments about what exactly constitutes equity or, recalling the discussion in section 2, fairness, are subjective and highly contentious in nature. For these reasons, this methodology does not, and likely *cannot*, determine whether any given distribution is equitable. Instead, it uses tools to *describe* the distribution. The fairness of the distribution is left to the opinion of the reader.

The first method to analyze the data involves a simple linear model of the relationship between each census block group's DI and the accessibility provided to it by transit. Comparisons are made separately for each of the time periods (morning peak, midday, and afternoon peak) and for each category of accessibility (total jobs, retail/shopping, education, health and social services, entertainment, jobs for high school education or lower, and jobs for some college / college

degree). The second method involves grouping census block groups into deciles based on their DI values. Bar plots for each time period and each category of accessibility are produced. The third method involves the creation of maps combining depictions of accessibility and disadvantage to produce a picture of “transit disadvantage.” Collectively, the presentation of information in these ways provides intelligence about the equity of transit service that may be used in addressing perceived shortfalls in meeting policy goals.

3.6 Comparing Accessibility II: Effects of a Service Change

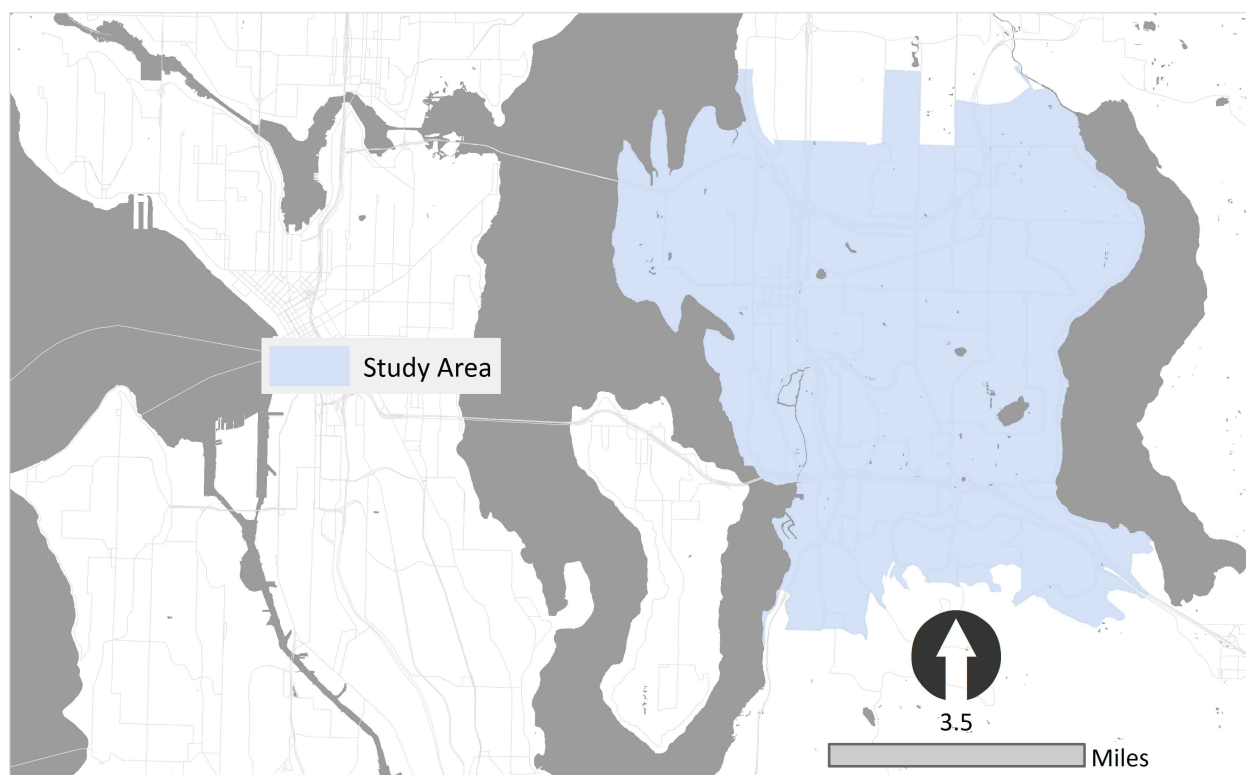
To demonstrate the methodology’s use in revealing changes in accessibility when the transit network is altered, a smaller sub-area was chosen to analyze. The network changes under analysis are derived from the differences between GTFS feeds of spring 2014 and spring 2015 (from both Metro and Sound Transit), which, most significantly, reflect the first round of Metro’s service reductions. These reductions cut 28 routes and revised 18 others (King County Metro 2014b). The following criteria guided the choice of sub-area to study:

- has a reasonable mix of high- and low-DI scores,
- covers a more central area generally well-served by transit,
- contains census block group geometries that are not unreasonably large (to avoid skewing of results), and
- covers an area directly affected by Metro’s September 2014 service reductions.

Collectively, these criteria ensure a reasonable level of validity of the illustration. The area chosen comprises 92 block groups covering parts of Bellevue and southwest Redmond between Lake Washington to the west, Lake Sammamish to the east, SR 520 to the north, and I-90 to the south (Figure 10).

It is important to note that although new accessibility scores are not calculated for the entire county, the new scores for sub-area block groups reflect the accessibility provided by the *entire network*, not a subset thereof; the entirety of the GTFS feeds are used to determine accessibility.

Figure 10. Secondary Study Area

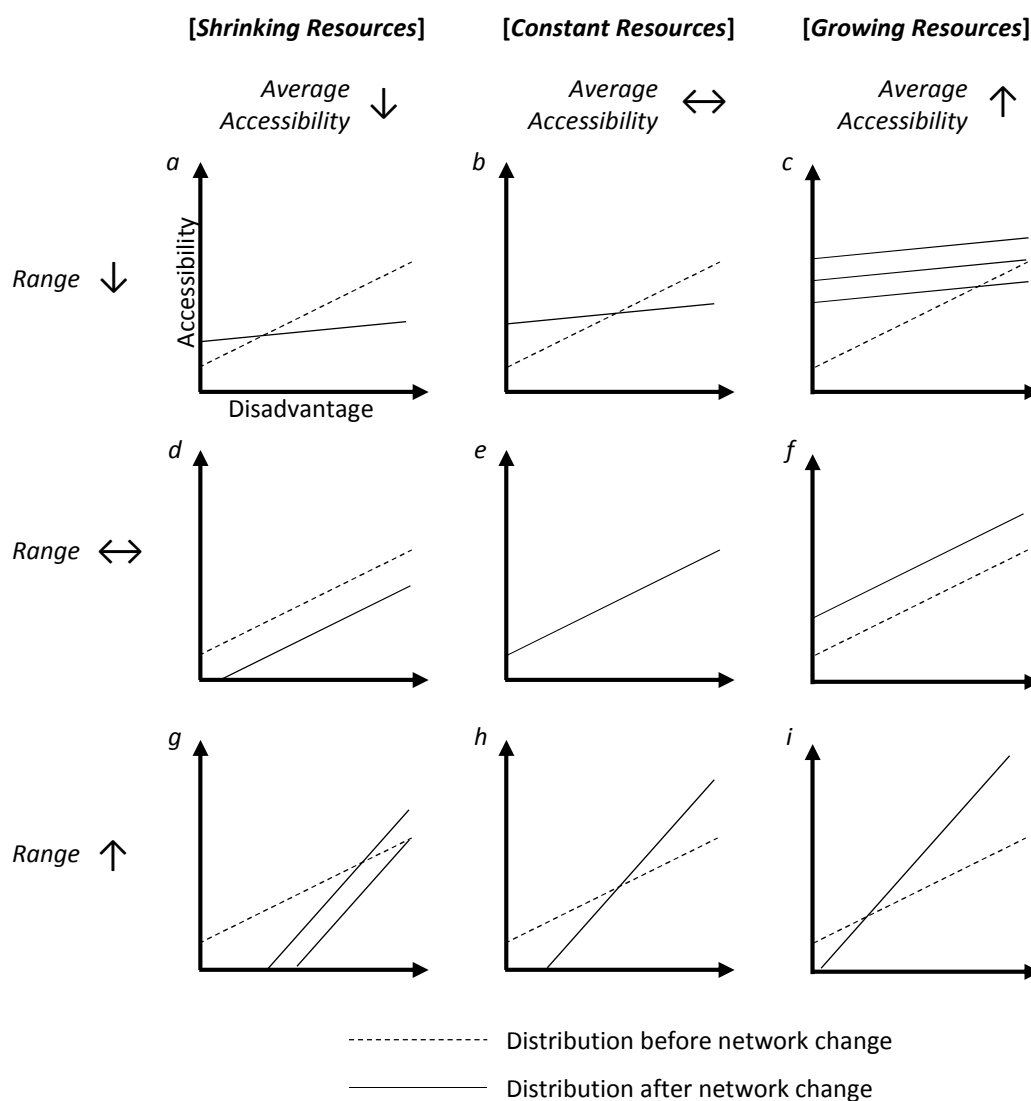


This illustration of the methodology's use is also constrained temporally: only the morning peak period is analyzed. This time period is the most logical choice when measuring accessibility to non-home destinations; most people travel away from home in the morning. Still, it does not provide a full picture of accessibility, especially for populations who may work odd hours and/or in part time jobs requiring home-to-work commutes at times outside this window.

The framework for this temporal analysis draws on the previous discussion of principles of fairness, particularly the concepts of average accessibility, range constraints, and minimum floors. Average accessibility and the range of accessibility values are easily computed, but the

range itself does not reveal who is experiencing the best and worst accessibility. Plotting the relationship between accessibility and disadvantage is therefore necessary. Figure 11 presents a matrix of potential changes in the distribution of accessibility (among disparate groups) resulting from a network change. Accessibility is represented on the y-axis, with the origin representing no accessibility. Disadvantage is represented on the x-axis, with the origin representing the least disadvantaged. The columns, from left to right, represent situations in which a network change decreased, had no effect on, and increased (respectively) the *average accessibility* of the system.

Figure 11. Matrix of Changes in Distributions



The rows, from top to bottom, represent situations in which a network change decreased, had no effect on, and increased (respectively) the *range* between the highest and lowest accessibility scores. Dotted lines represent a best-fit to hypothetical data points¹⁷ gained from a measurement of accessibility *before* the network change; these are identical in each graph. Solid lines represent the best-fit to hypothetical data points gained from a measurement of accessibility *after* the network change. For clarity, a minimum acceptable accessibility is not shown, but a horizontal line could be placed at any arbitrary level of accessibility to represent this minimum. So long as the relationship between accessibility and disadvantage is statistically significant, two traits of the best-fit lines in these graphs will assist in the analysis: their slope, and whether or not they shift up or down (or left and right if one conceives of them as supply curves). An increase in slope, for example, may indicate the range has increased, while a decrease in slope may indicate the opposite. A shift up represents an increase in average accessibility, while a shift down represents a decrease. Lastly, the extreme left and right data points represent the least and most disadvantaged members of society, respectively.

As an example, graph *a* is representative of a network change that reduced the average accessibility: the area below the solid line is less than the area below the dotted line. In this example, the range between the highest and lowest accessibility provided by the system decreased: the slope of the solid line is lower than the slope of the dotted line. It is also clear that the accessibility of the least disadvantaged member of society improved (left-most data point), while the accessibility of the most disadvantaged member of society worsened (right-most data point). On the opposite end of the spectrum, graph *i* represents a situation in which a network

¹⁷ These data points (not depicted) compose a scatterplot of accessibility against disadvantage for each analysis zone being studied. As will be seen, some distributions conform to the general upward slope, and some do not.

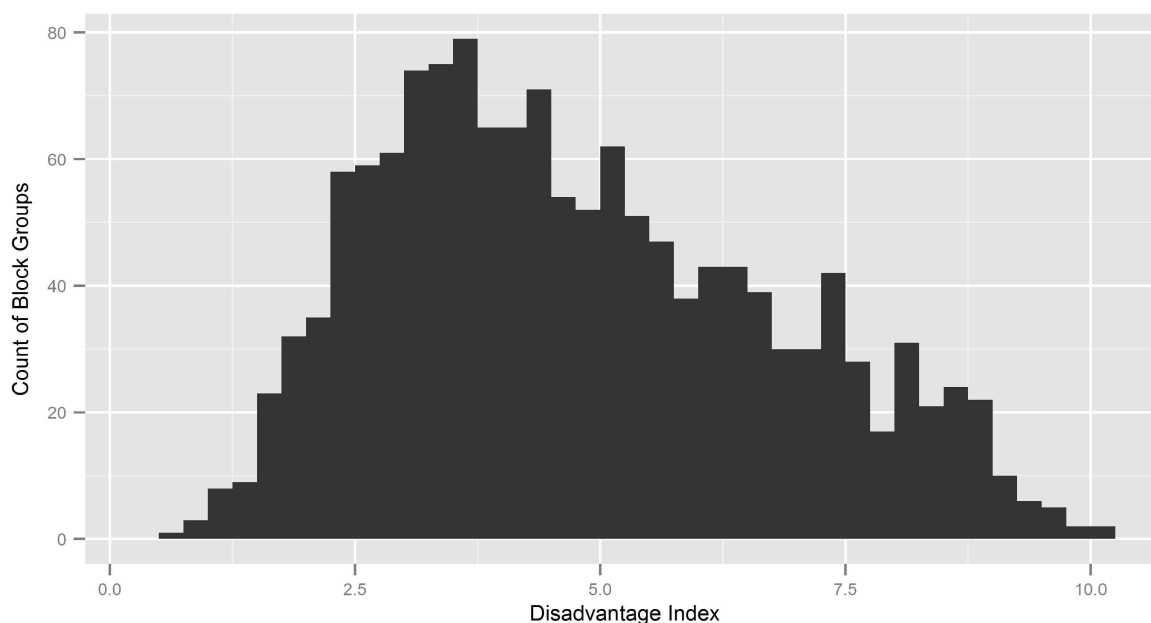
change increased both the average accessibility and the range between best and worst off. However, the most disadvantaged member of society witnessed a significant increase in accessibility, while the opposite occurred for the least disadvantaged member. Results of the analysis performed will be evaluated in this framework in Section 5.

4 Results

4.1 Disadvantage Index

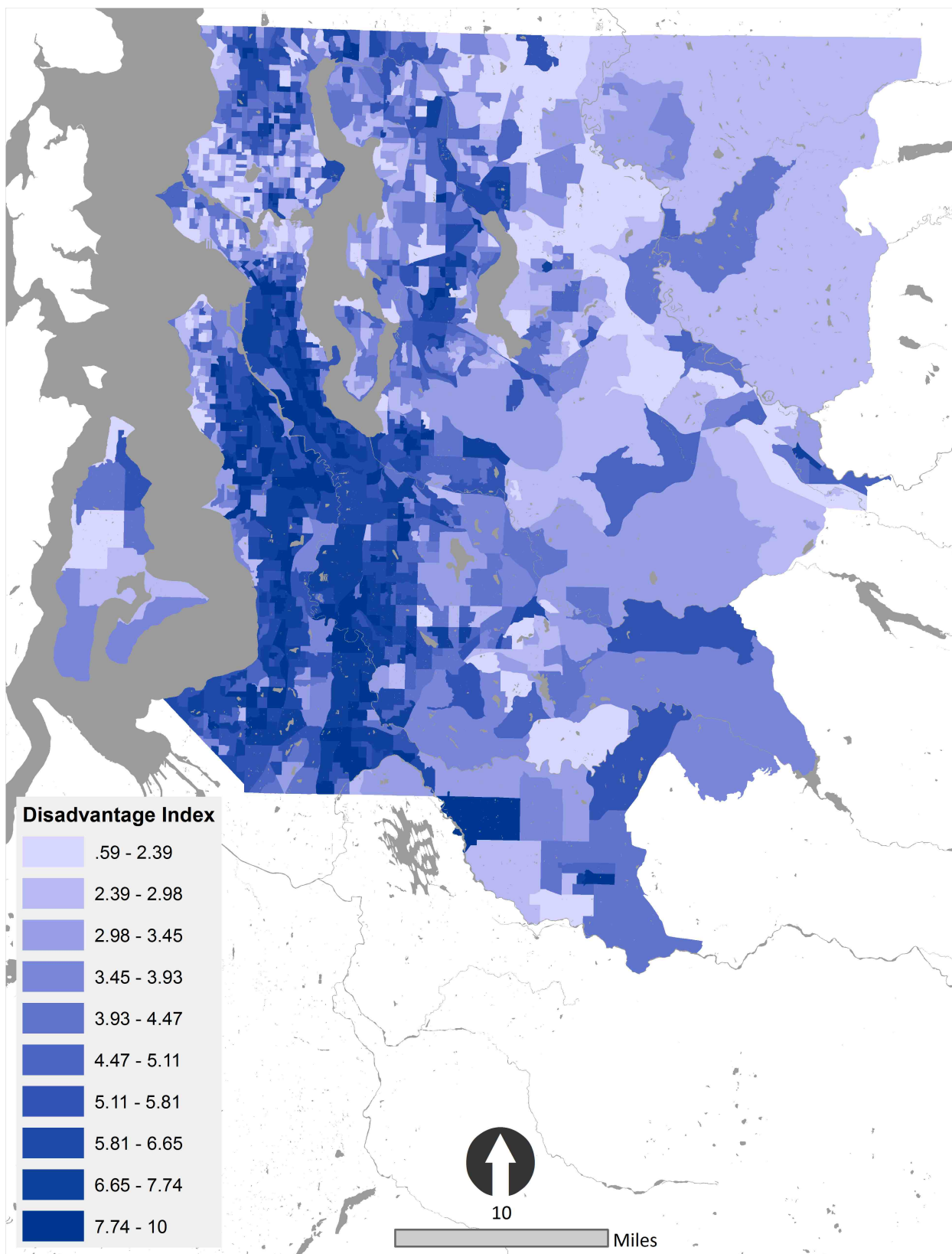
A histogram of DI scores is presented in Figure 12, and Figure 13 depicts DI values throughout the county.

Figure 12. Histogram of Disadvantage Index Scores



Concentrations of high levels of composite disadvantage are exhibited in west-central and southwest portions of the county. This area is interrupted by a north-south line of relatively less disadvantage corresponding to the I-5 corridor. The far northwest and an arc extending east and then south also show high levels of disadvantage. Eastern portions of the county exhibit mixed levels of moderate to low disadvantage, as do central parts of Seattle.

Figure 12. Disadvantage Index Map



4.2 Change in Corridor Scores

Table 6 lists each corridor (as defined in spring 2014), its social equity score under the 2014 Guidelines analysis, and its social equity score with the two revised scoring methodologies.

Table 6. Social Equity Corridor Score Comparison: Existing and Revised Methodology

ID	Between	And	Major Route	Existing Method (EM)	Revised Method 1 (M1)	Revised Method 2 (M2)	Comparison	
							M1 - EM	M2 - EM
1	Admiral District	Southcenter	128	5	7	10	+2	+5
2	Alki	SODO	50	5	3	0	-2	-5
3	Auburn	Burien	180	10	9	10	-1	-
4	Auburn	Federal Way	181	5	8	10	+3	+5
5	Aurora Village	Seattle CBD	E Line	5	5	4	-	-1
6	Aurora Village	Northgate	346	5	5	5	-	-
7	Avondale	Kirkland	248	10	3	0	-7	-10
8	Ballard	U District	48	0	1	0	+1	-
9	Ballard	Northgate	40	0	3	0	+3	-
10	Ballard	Seattle CBD	D Line	0	2	0	+2	-
11	Ballard	U District	44	0	2	0	+2	-
12	Ballard	Seattle CBD	40	0	2	0	+2	-
13	Beacon Hill	Seattle CBD	36	10	9	10	-1	-
14	Bellevue	Eastgate	271	10	6	7	-4	-3
15	Bellevue	Redmond	B Line	5	6	6	+1	+1
16	Bellevue	Renton	240	10	5	4	-5	-6
17	Burien	Seattle CBD	120	5	8	10	+3	+5
18	Burien	Seattle CBD	131	10	8	10	-2	-
19	Burien	Seattle CBD	132	10	9	10	-1	-
20	Capitol Hill	White Center	60	10	9	10	-1	-
21	Capitol Hill	Seattle CBD	10	5	3	0	-2	-5
22	Capitol Hill	Seattle CBD	12	5	3	1	-2	-4
23	Central District	Seattle CBD	3/4	10	7	10	-3	-
24	Colman Park	Seattle CBD	27	10	7	8	-3	-2
25	Cowen Park	Seattle CBD	71E-74E	10	6	7	-4	-3
26	Discovery Park	Seattle CBD	33	0	3	1	+3	+1
27	Eastgate	Bellevue	241	5	5	3	-	-2
28	Eastgate	Bellevue	246	5	5	4	-	-1
29	Eastgate	Overlake	226	0	6	6	+6	+6
30	Enumclaw	Auburn	186/915	5	7	9	+2	+4
31	Fairwood	Renton	148	5	7	9	+2	+4
32	Federal Way	SeaTac	A Line	10	10	10	-	-
33	Federal Way	Kent	183	10	8	10	-2	-
34	Fremont	Seattle CBD	26/28	0	4	2	+4	+2
35	Fremont	U District	31/32	0	1	0	+1	-
36	Fremont	Whittier Heights	28	0	0	0	-	-
37	Green River CC	Kent	164	5	8	10	+3	+5
38	Greenwood	Seattle CBD	5	0	2	0	+2	-
39	High Point	Seattle CBD	21	10	5	5	-5	-5

40	Issaquah	Eastgate	271	5	3	0	-2	-5
41	Issaquah	Overlake	269	5	3	1	-2	-4
42	Issaquah	North Bend	208/209	0	2	0	+2	-
43	Kenmore	Kirkland	234	0	2	0	+2	-
44	Kenmore	Shoreline	331	0	3	1	+3	+1
45	Kenmore	U District	372E	0	4	2	+4	+2
46	Kenmore	Totem Lake	935	0	3	0	+3	-
47	Kennydale	Renton	909	10	7	8	-3	-2
48	Kent	Burien	166	10	7	9	-3	-1
49	Kent	Maple Valley	168	0	6	7	+6	+7
50	Kent	Renton	169	10	8	10	-2	-
51	Kent	Seattle CBD	150	10	8	10	-2	-
52	Kent	Renton	153	10	9	10	-1	-
53	Kirkland	Bellevue	234/235	0	1	0	+1	-
54	Kirkland	Factoria	245	5	5	5	-	-
55	Lake City	Seattle CBD	41	10	7	8	-3	-2
56	Northgate	U District	75	0	3	1	+3	+1
57	Lake City	U District	65	0	3	0	+3	-
58	Laurelhurst	U District	25	0	2	0	+2	-
59	Madison Park	Seattle CBD	11	5	3	0	-2	-5
60	Madrona	Seattle CBD	2	5	4	3	-1	-2
61	Magnolia	Seattle CBD	24	0	2	0	+2	-
62	Mercer Island	S Mercer Island	202/204	0	1	0	+1	-
63	Mirror Lake	Federal Way	901	10	9	10	-1	-
64	Mount Baker	Seattle CBD	14	10	8	10	-2	-
65	Mountlake Terrace	Northgate	347	0	3	1	+3	+1
66	Mount Baker	U District	48	10	4	3	-6	-6
67	NE Tacoma	Federal Way	182	5	5	5	-	-
68	Northgate	U District	66E/67	5	4	2	-1	-3
69	Northgate	Seattle CBD	16	0	3	1	+3	+1
70	Northgate	U District	68	5	3	0	-2	-5
71	Othello Station	SODO	50	5	6	7	+1	+2
72	Eastgate	Bellevue	226	10	3	1	-7	-9
73	Overlake	Bellevue	249	0	3	0	+3	-
74	Pacific	Auburn	917	10	9	10	-1	-
75	Queen Anne	Seattle CBD	2/13	5	3	1	-2	-4
76	Queen Anne	Seattle CBD	3/4	5	4	2	-1	-3
77	Rainier Beach	Seattle CBD	7	10	9	10	-1	-
78	Rainier Beach	Seattle Center	8	5	7	10	+2	+5
79	Rainier Beach	Capitol Hill	9E	10	8	10	-2	-
80	Redmond	Eastgate	221	5	4	2	-1	-3
81	Redmond	Totem Lake	930	6	5	6	+1	-
82	Redmond	Fall City	224	5	2	0	-3	-5
83	Renton	Burien	140	10	9	10	-1	-
84	Renton	Seattle CBD	101/102	10	8	10	-2	-
85	Renton	Rainier Beach	107	10	9	10	-1	-
86	Renton	Seattle CBD	106	10	9	10	-1	-
87	Renton	Renton Highlands	105	10	8	10	-2	-
88	Renton	Enumclaw	143E/907	0	3	1	+3	+1
89	Renton Highlands	Renton	908	10	7	9	-3	-1
90	Richmond Beach	Northgate	348	5	5	4	-	-1
91	South Vashon	North Vashon	118	0	1	0	+1	-
92	Sand Point	U District	30	5	4	2	-1	-3

93	Shoreline	U District	373E	5	5	4	-	-1
94	Shoreline CC	Northgate	345	5	5	4	-	-1
95	Shoreline CC	Lake City	330	0	6	6	+6	+6
96	Shoreline CC	Greenwood	5	0	3	1	+3	+1
97	Totem Lake	Seattle CBD	255	0	2	0	+2	-
98	Woodinville	Kirkland	236	0	2	0	+2	-
99	Tukwila	Seattle CBD	124	10	8	10	-2	-
100	Tukwila	Des Moines	156	10	8	10	-2	-
101	Tukwila	Fairwood	906	5	6	6	+1	+1
102	Twin Lakes	Federal Way	903	10	8	10	-2	-
103	Twin Lakes	Federal Way	187	5	7	9	+2	+4
104	U District	Seattle CBD	70-73	5	4	2	-1	-3
105	U District	Seattle CBD	49	5	3	1	-2	-4
106	U District	Bellevue	271	5	2	0	-3	-5
107	U District	Seattle CBD	25	5	2	0	-3	-5
108	UW Bothell	Redmond	931	0	1	0	+1	-
109	UW Bothell	Kirkland	238	0	3	0	+3	-
110	Wedgwood	Cowen Park	71E	0	1	0	+1	-
111	West Seattle	Seattle CBD	C Line	0	3	1	+3	+1
112	White Center	Seattle CBD	125	5	6	6	+1	+1

Source: King County Metro (2014a)

The current Guidelines method results in the bulk of corridors (72 of 112) receiving either 0 or 10 points; the remainder receive the only other possible score: 5 points. Method 1 results in a more normal distribution of corridor scores, with fewer corridors appearing on the fringes (Figure 13). Method 2 retains the bulk of corridors (61) within either the minimum or maximum score, with a fairly even distribution over the remaining score possibilities. As illustrated in Figures 14 and 15, Method 1 results in a larger number of smaller score changes, with an average score change of -0.06. Method 2 results in a fewer number of corridors changing score, but the changes are larger when they do occur; the average score change using this method is -0.51.

The results provide more granular detail of the differences between corridors with respect to the demographic makeup of their service areas. Contrary to the existing method, the revised methods also ensure that nearly everyone counts in the computation of the social equity score. This is accomplished with little increase in complexity. These results will be discussed in section 5.

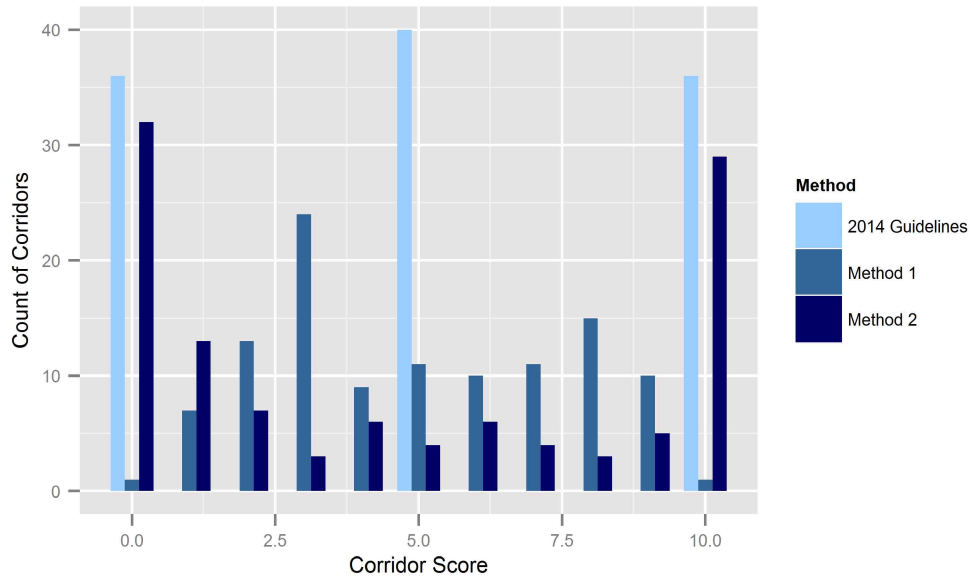
Figure 13. Histograms of Corridor Scoring Methodologies

Figure 14. Corridor Score Changes: Methodology 1

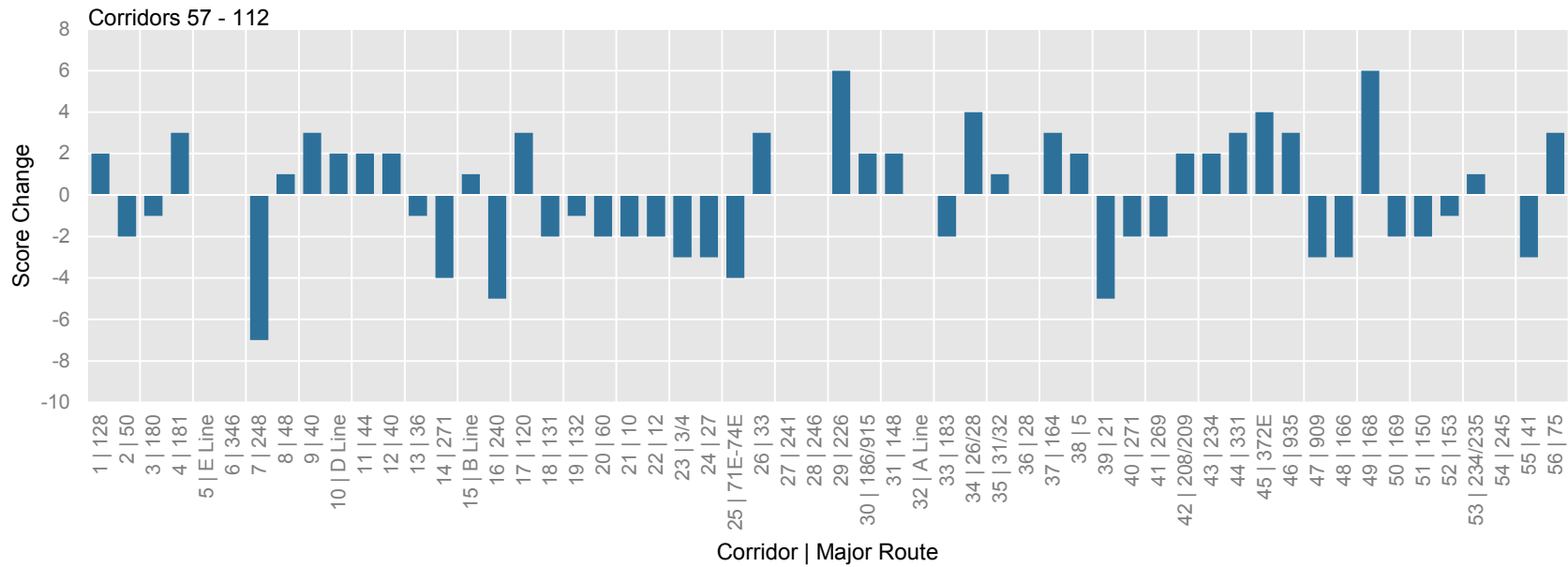
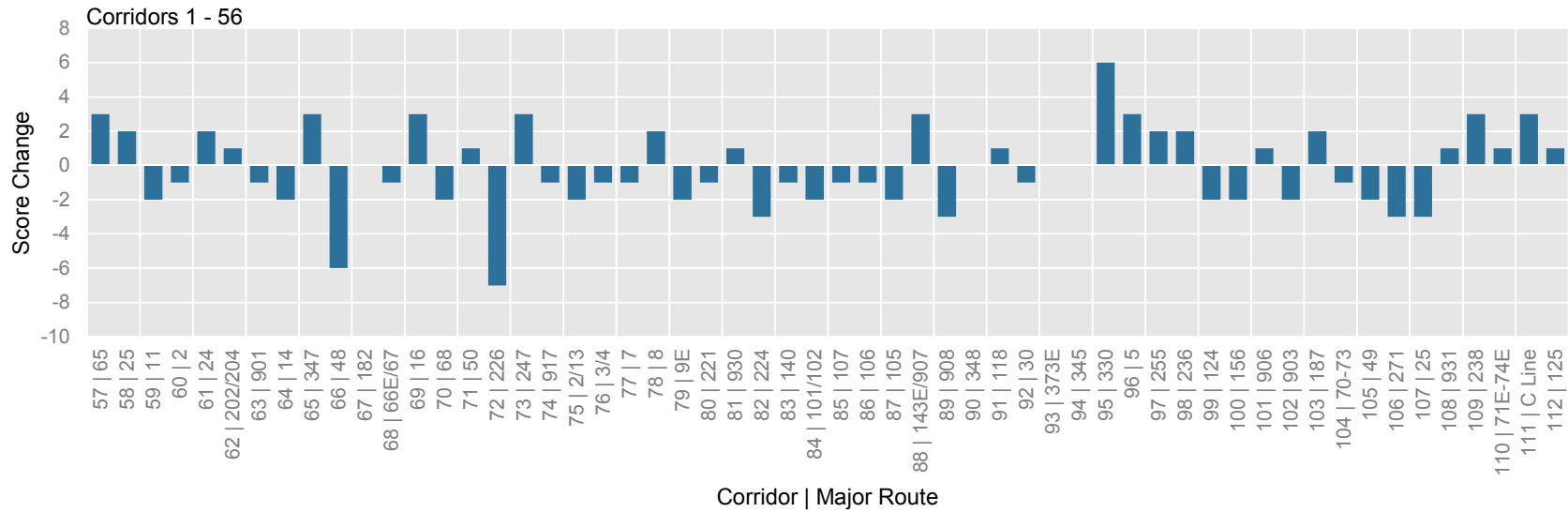
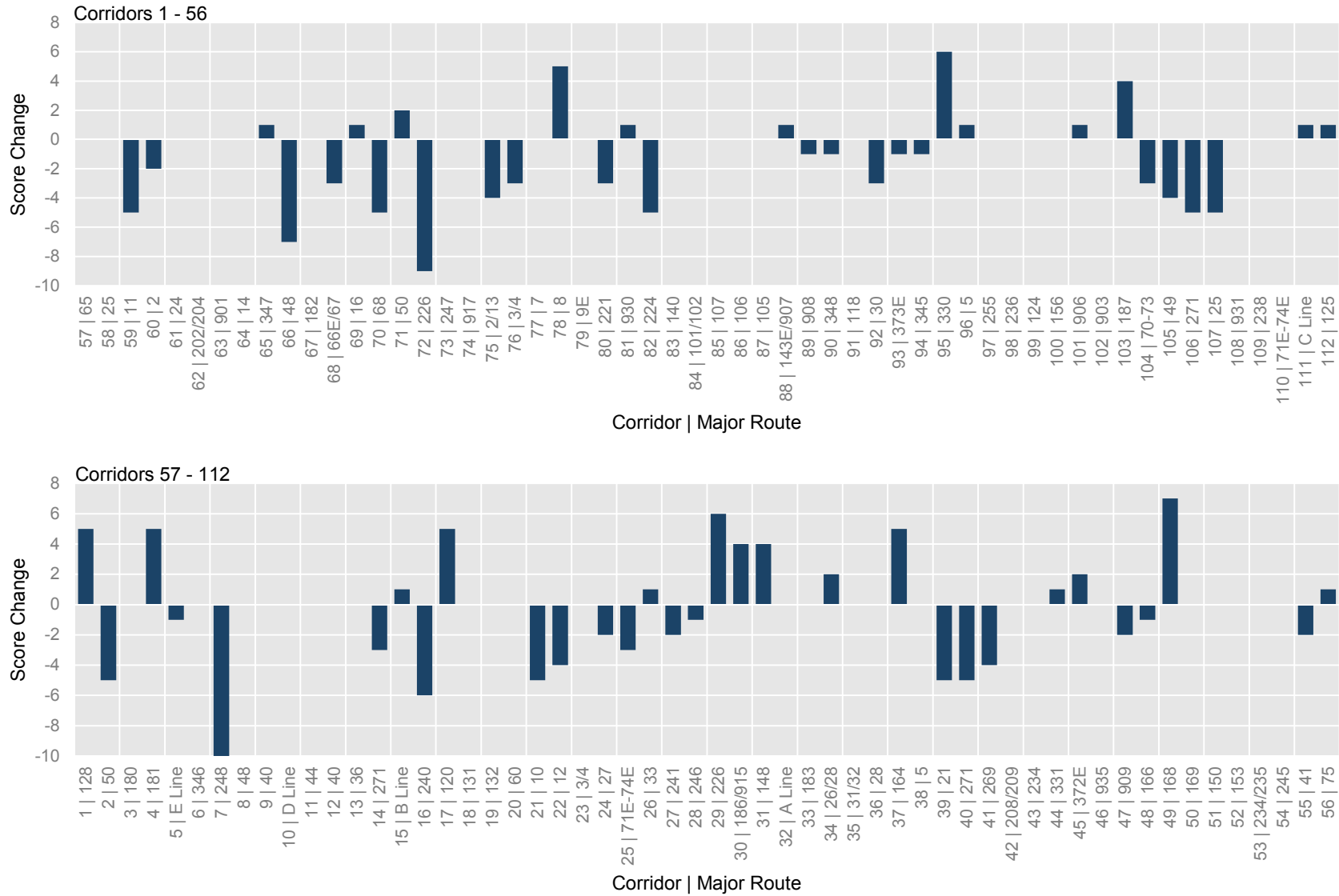


Figure 15. Corridor Score Changes: Methodology 2



4.3 Disparities in Accessibility I: Snapshot in Time

For simplicity of presentation, accessibility values for only the morning peak period are depicted in Figure 16. The relative access scores for this period are largely consistent with the Access Across America study (Owen and Levinson 2014). The pages following Figure 16 contain scatterplots of the Disadvantage Index against the following:

- access to opportunity
- access to health care / social services
- access to retail/shopping
- access to education
- access to entertainment
- access to jobs (classified with an educational level of high school or less)
- access to jobs (classified with an education level of some college or a college degree)

These categories were created by subsetting LEHD data based on NAICS codes, as detailed in section 3.4.2. Seven plots each are shown for the morning peak period first (Figure 17), then midday (Figure 18), then the afternoon peak (Figure 19). Linear regressions are plotted in blue, and 95% confidence intervals are shown in dark gray. Descriptive statistics of the regressions are shown above each plot.

All regressions save one (midday access to jobs classified as high school education or less) exhibit a negative r^2 , indicating a horizontal line fits the data better. Only two of the relationships exhibit statistical significance: access to education (AM) and access to retail/shopping (PM). Even for these, the explanatory power of the model is very low, indicating that county-wide, there is no significant relationship between the Disadvantage Index and the access provided by transit to any set of destinations as defined in the methodology during any time period studied. In short, a block group's *composite* disadvantage does not predict its level of accessibility via transit.

Figure 16. Access to Opportunity, Morning Peak

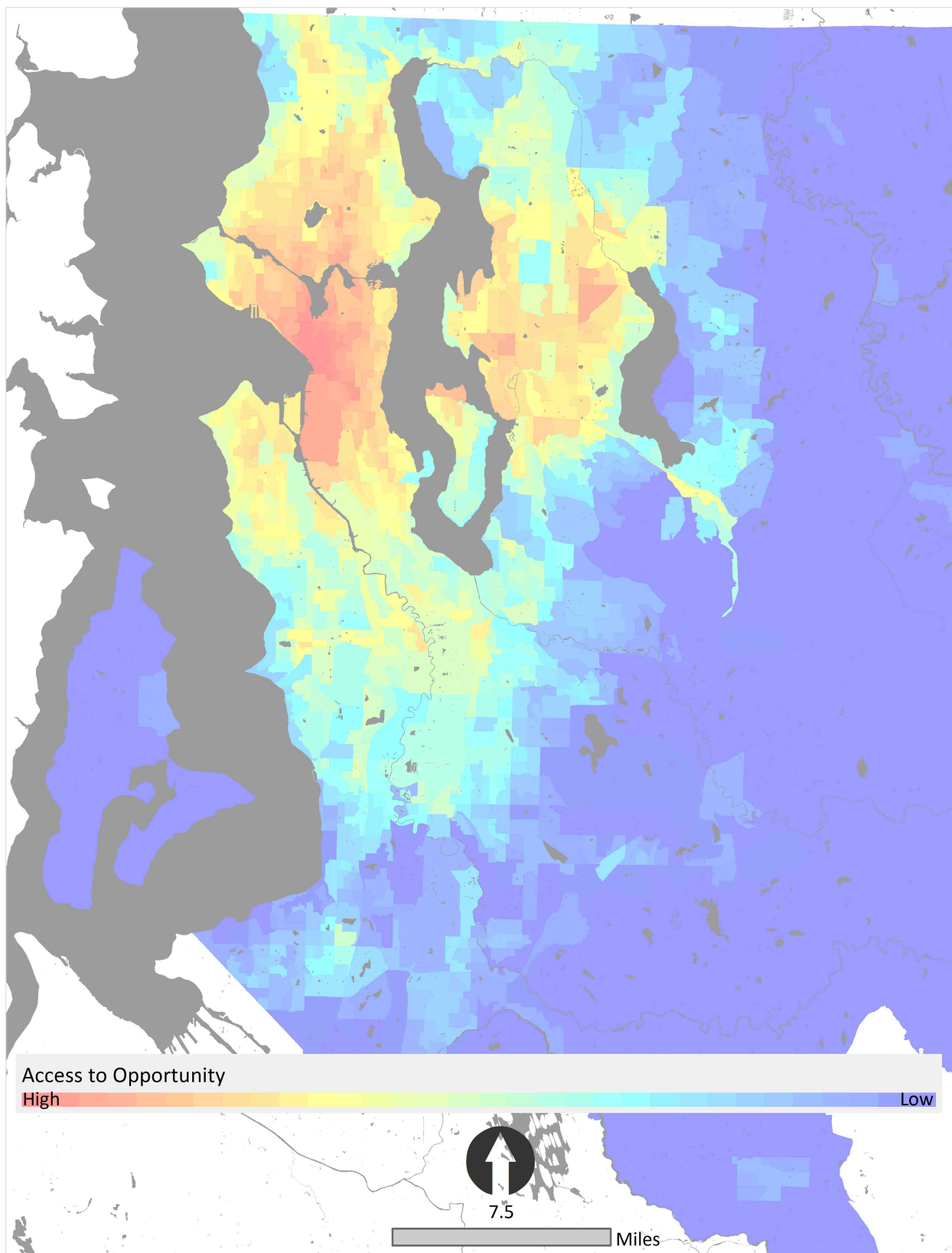


Figure 17. Access to Opportunity (All Categories) by Disadvantage Index, Morning Peak

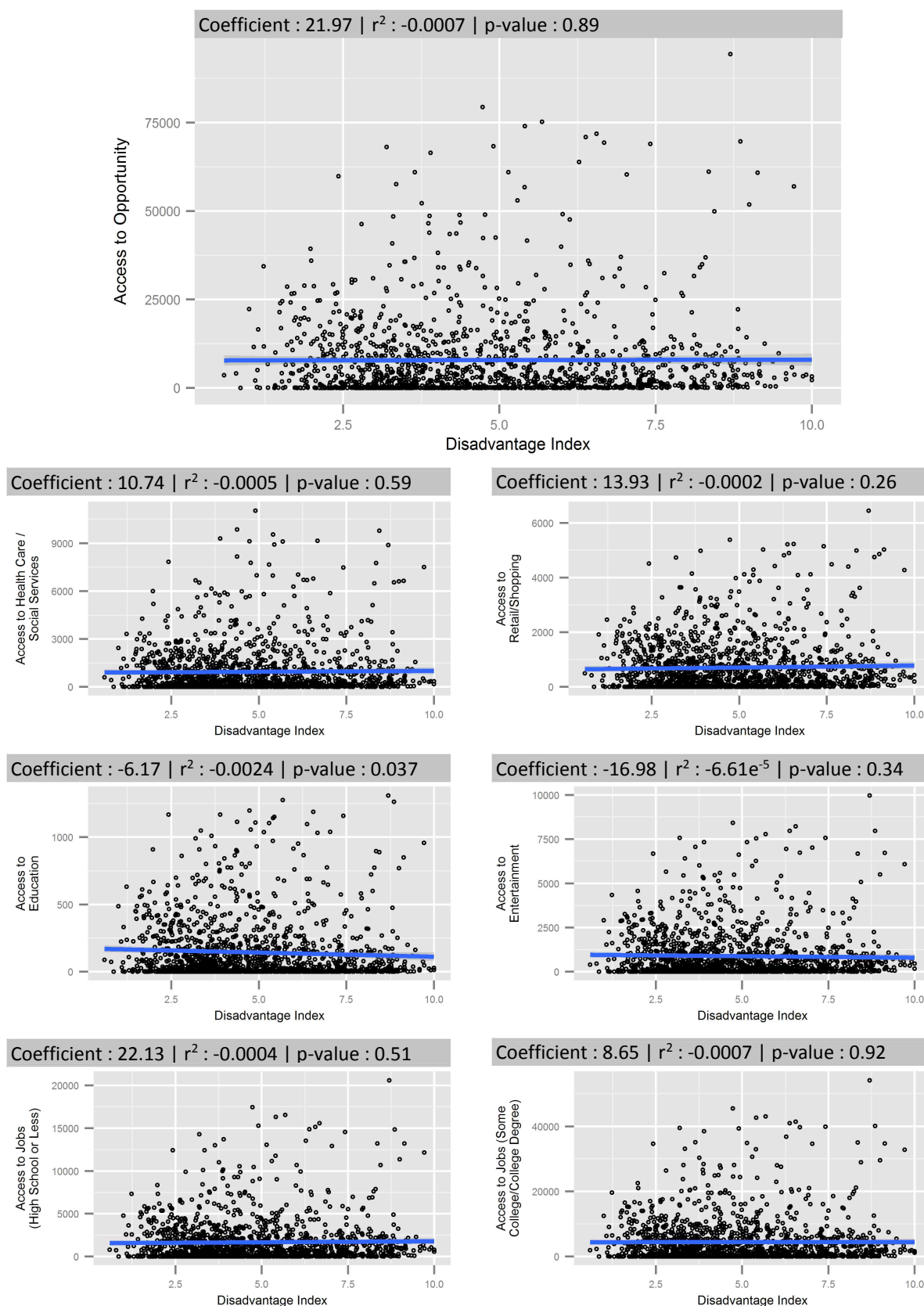


Figure 18. Access to Opportunity (All Categories) by Disadvantage Index, Midday

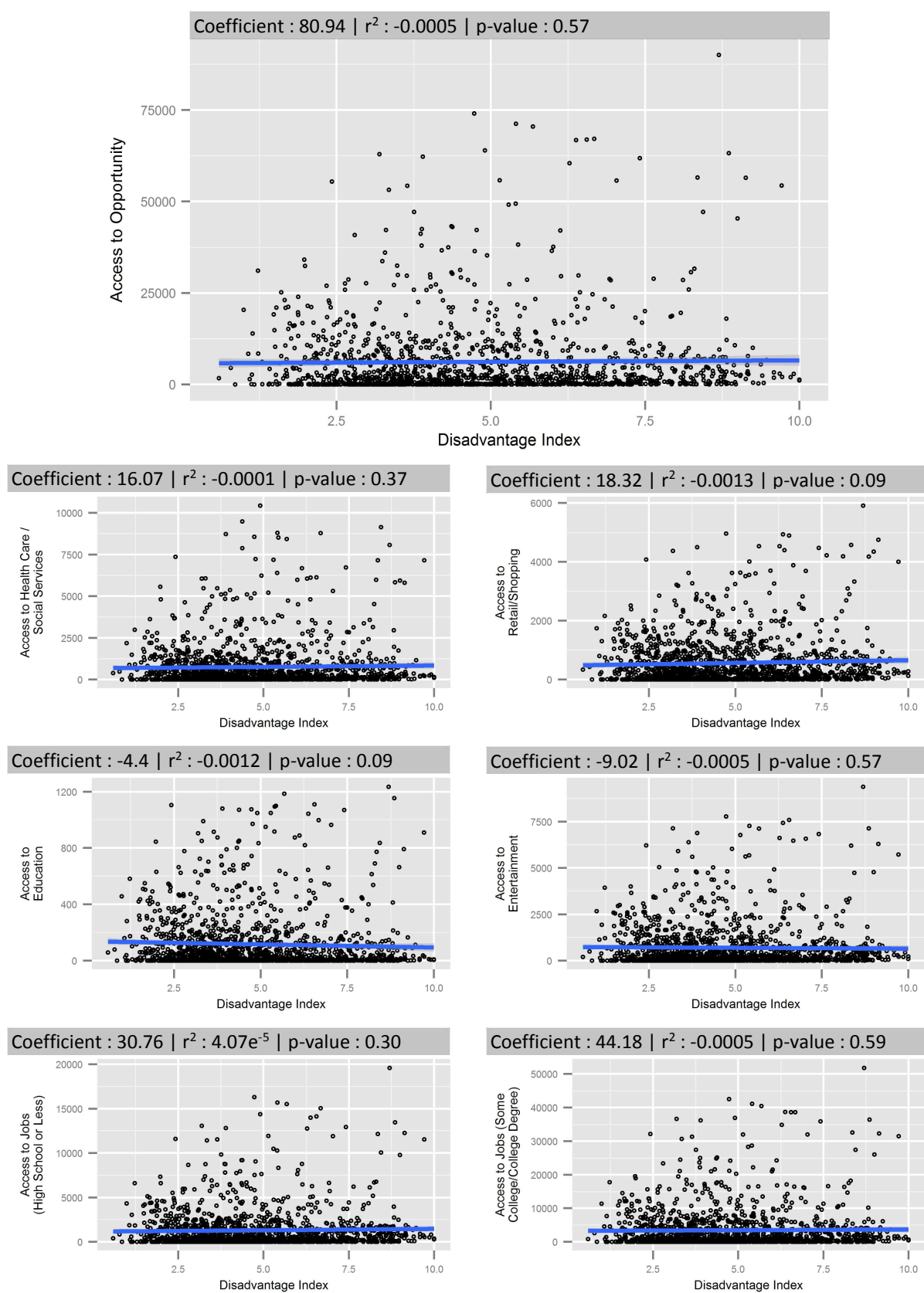
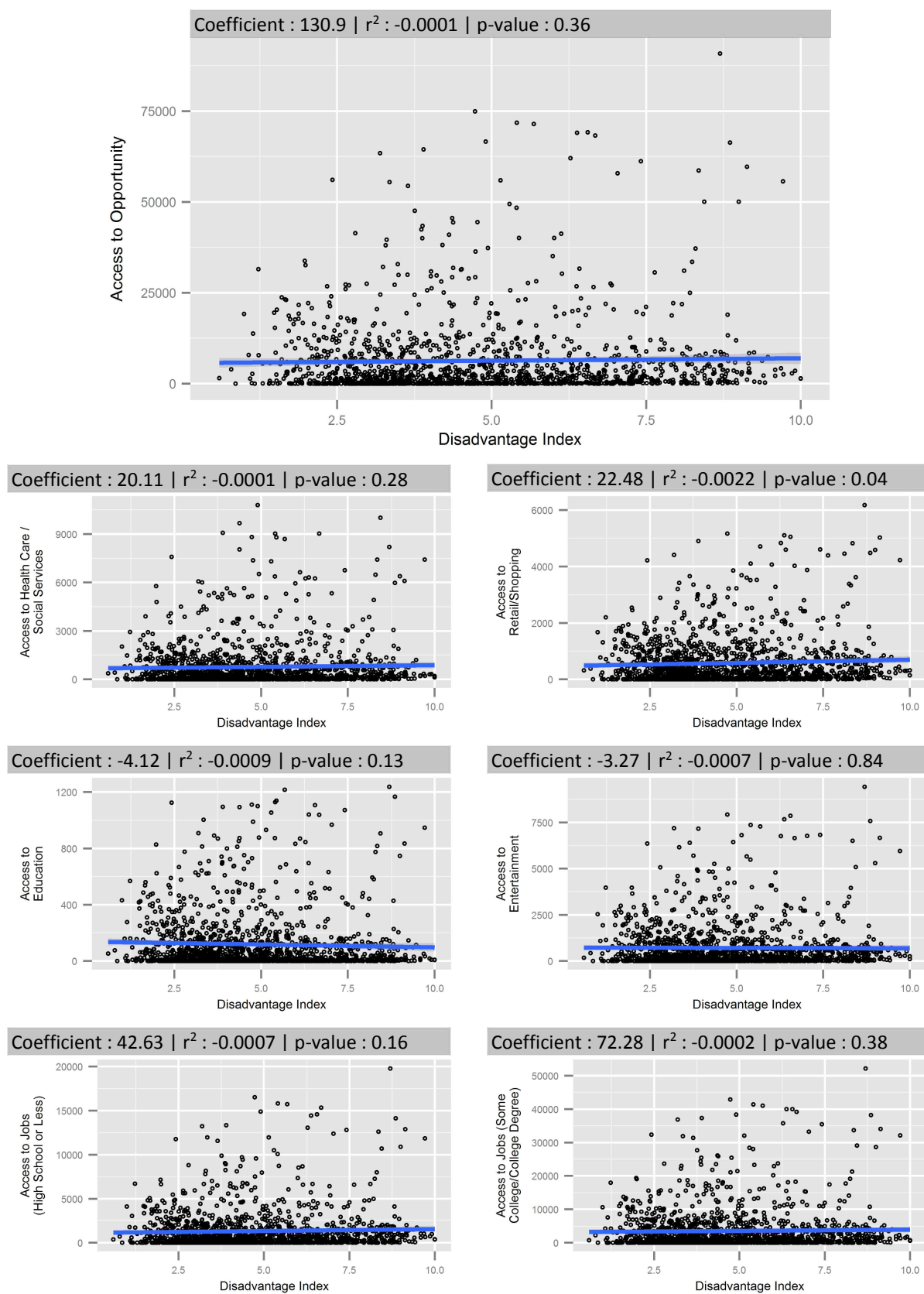


Figure 19. Access to Opportunity (All Categories) by Disadvantage Index, Afternoon Peak



Next, combination bar graphs are presented (Figure 20). As described in the methodology, block groups are divided into deciles of disadvantage based on their Disadvantage Index values. Seven plots are presented, representing access to the same seven sets of destinations as above. The three time periods studied are shown as separate series side by side in each graph.

The morning peak period exhibits the highest level of accessibility. The midday and evening peak periods lag behind, with evening peak accessibility exceeding that of the midday period in nearly every destination set and decile of disadvantage. A pattern emerges in the plots, with the least disadvantaged decile (farthest to the left) enjoying higher accessibility levels than at least the several next more disadvantaged deciles. Accessibility then appears to increase through the mid-range, falling off again in the eighth and ninth deciles before rebounding in the most disadvantaged decile. Compared to the other destination sets, access to education drops off more quickly and rebounds less in the most disadvantaged decile. For comparative purposes with Figure 16 above, Figure 21 shows access to education, also in the morning peak period.

Figures 22 through 28 are composite images depicting each block group's Disadvantage Index and its accessibility value for each category in the morning peak period. Deep purple tones represent areas with high disadvantage *and* low access to various opportunities via transit; this can be viewed as transit disadvantage. The composite maps represent a rich tool for visual analysis and clearly show that southwest King County has widespread high disadvantage and low access to various opportunities via transit. The northwest (north Seattle) exhibits the same traits, as do isolated pockets farther east. No significant variations in accessibility emerge based on the particular set of destinations being analyzed.

Figure 20. Average Access to Opportunity by Decile of Disadvantage, All Time Periods

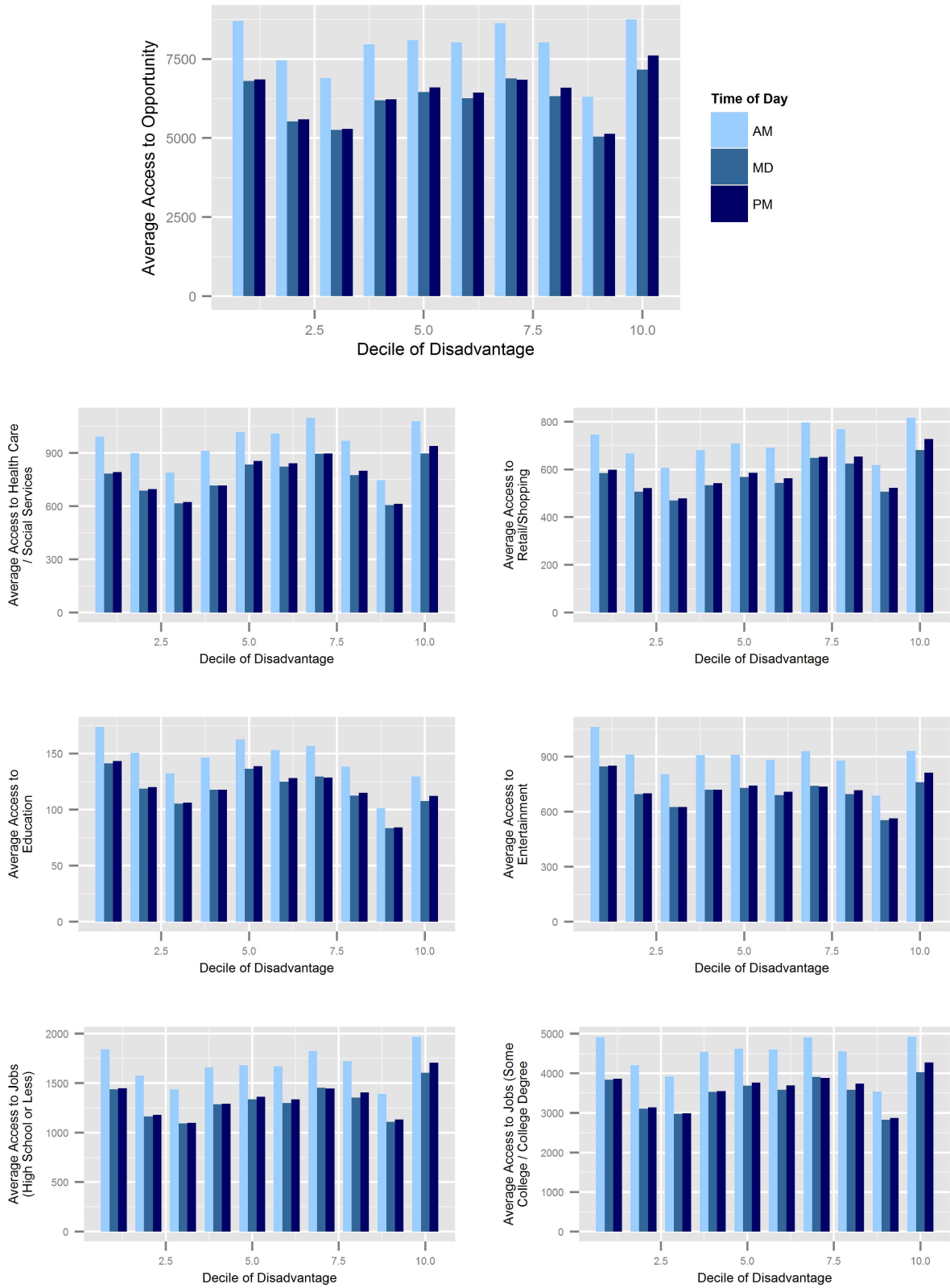


Figure 21. Access to Education, Morning Peak

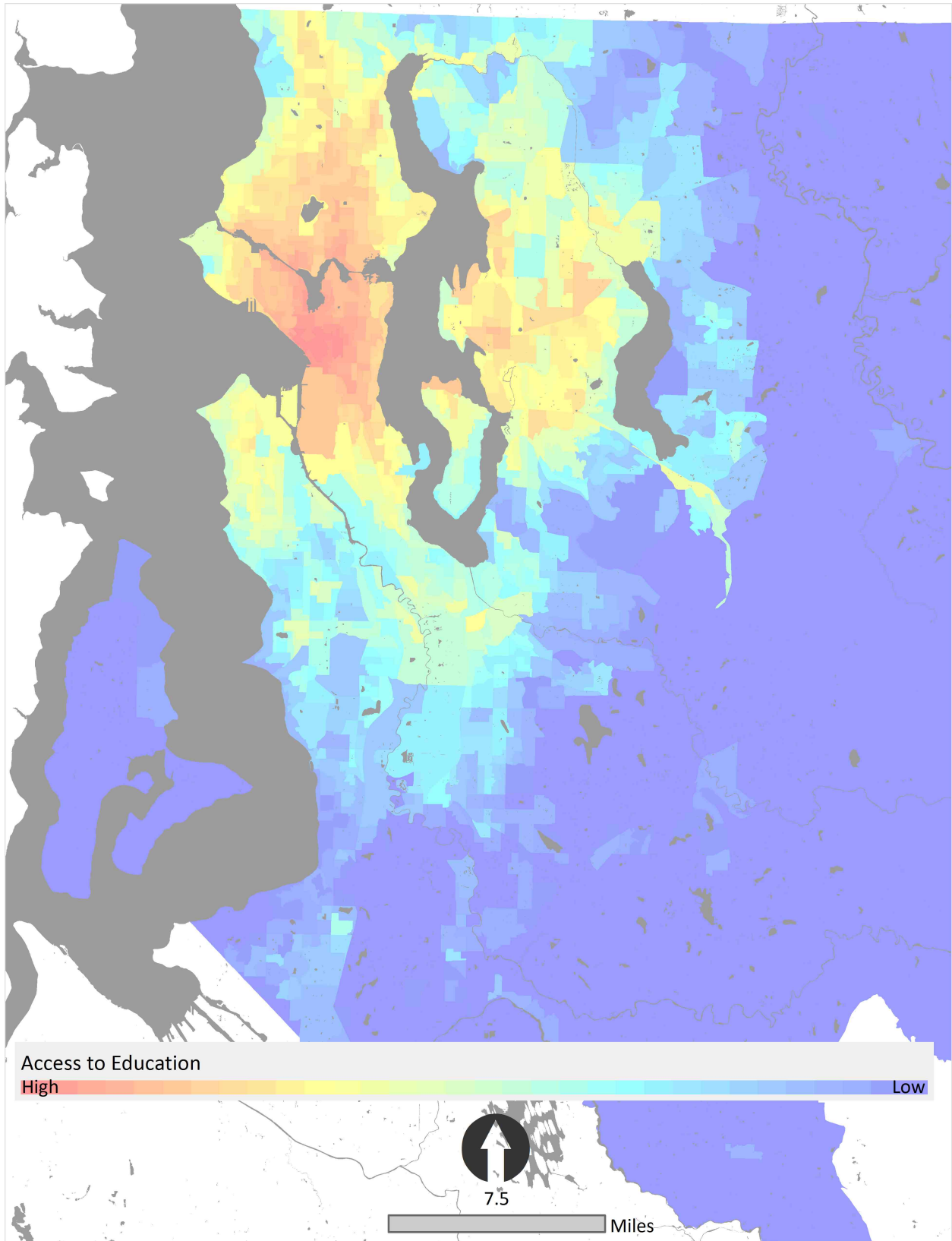


Figure 22. Transit Disadvantage for All Opportunities, Morning Peak



Figure 23. Transit Disadvantage for Health Care / Social Services, Morning Peak



Figure 24. Transit Disadvantage for Retail / Shopping, Morning Peak



Figure 25. Transit Disadvantage for Education, Morning Peak



Figure 26. Transit Disadvantage for Entertainment, Morning Peak



Figure 27. Transit Disadvantage for Jobs (High School or Less), Morning Peak



Figure 28. Transit Disadvantage for Jobs (Some College / College Degree), Morning Peak

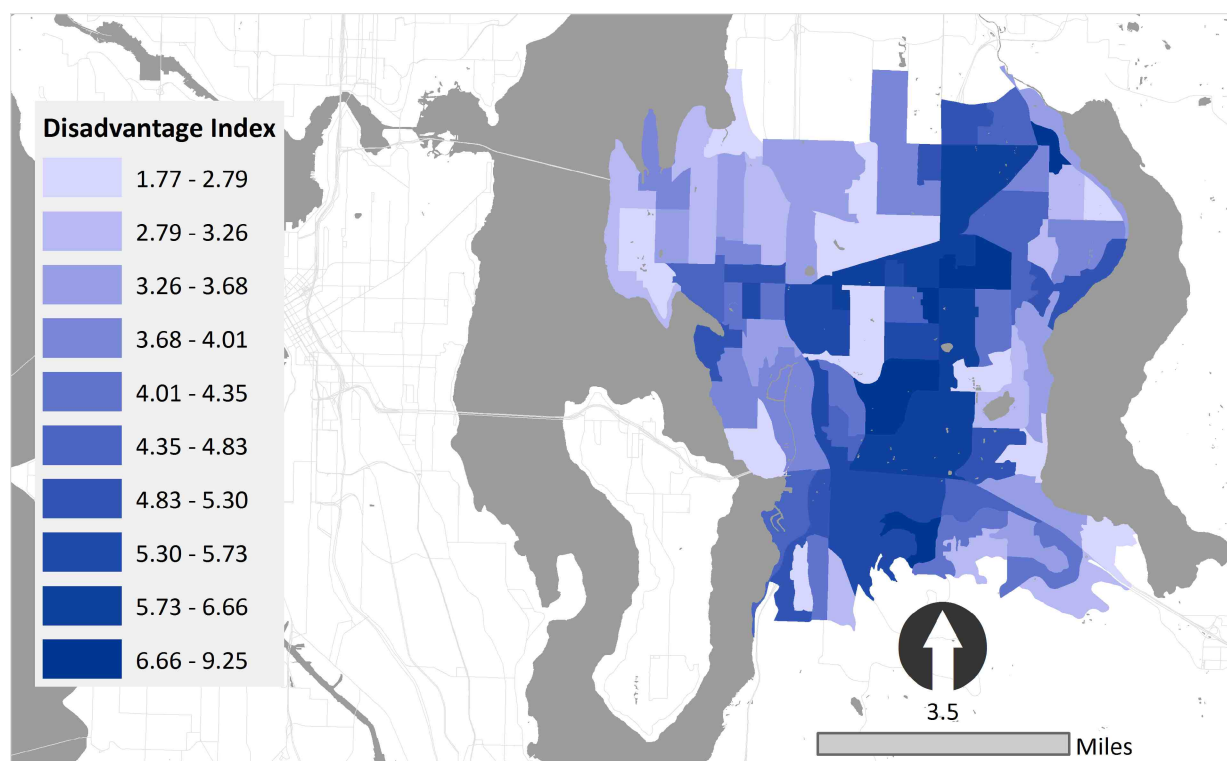


4.3 Disparities in Accessibility II: Effects of a Service Change

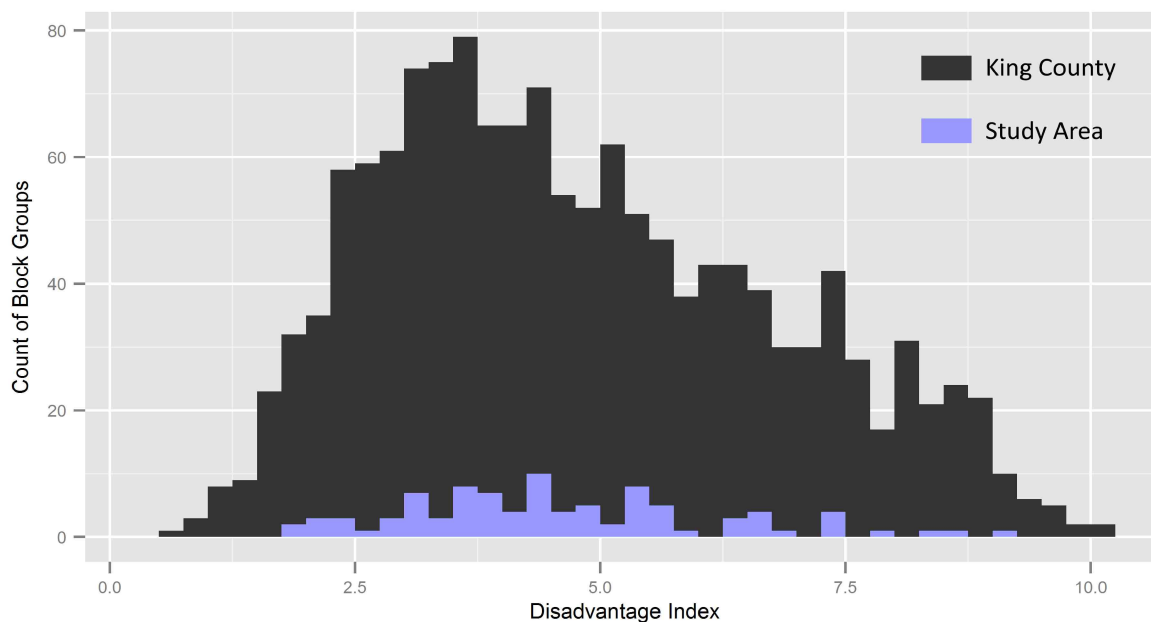
Figure 29 shows DI values in the sub-area chosen to analyze the effects of network changes.

Figure 30 shows the histogram of DI scores compared to that of the county; the study area is seen to be somewhat representative of the county as a whole. Table 7 catalogs the descriptive statistics of accessibility across all categories before and after the network change.

Figure 29. Disadvantage Index: Secondary Study Area



As would be expected from an overall reduction in service, average accessibility in all categories decreased due to the service change, but the overall change was relatively minor. In all but one category (access to college-level jobs), the range between worst and best accessibility increased. The slope of the best-fit line decreased for access to opportunity and college-level jobs, remained relatively constant for access to retail/shopping (not statistically significant) and education, and increased for access to health care / social services, entertainment (not statistically significant), and jobs classified as requiring a high school education or less.

Figure 30. Histogram of DI Values: Primary and Secondary Study Areas**Table 7.** Descriptive Statistics of Access Before and After Service Change

		Mean Access	% Change in Mean Access	Range	Intercept	Coefficient (DI)	r ²	p-value
Access to Opportunity	Before	10,229		31,786	5,239	1,088	.056	.013
	After	10,047	-1.78	33,605	5,070	1,086	.053	.015
Access to Health Care / Social Services	Before	920		3,676	483	95	.045	.024
	After	913	-0.76	3,808	473	96	.042	.028
Access to Retail/Shopping	Before	906		3,865	516	85	.025	.072
	After	901	-0.55	4,053	510	85	.023	.082
Access to Education	Before	155		457	95	13	.035	.041
	After	152	-1.94	461	93	13	.032	.048
Access to Entertainment	Before	847		3,349	542	66	.016	.120
	After	834	-1.53	3,525	525	67	.015	.126
Access to Jobs (High School or Less)	Before	1,726		5,442	995	159	.039	.033
	After	1,697	-1.68	5,845	961	161	.037	.036
Access to Jobs (Some College / College Degree)	Before	6,225		20,424	3,008	702	.064	.009
	After	6,109	-1.86	19,465	2,905	699	.062	.010

Before-and-after scatterplots and linear regressions are shown for each category of accessibility in Figures 31 through 37.

Figure 31. Access to Opportunity: Before and After Network Change

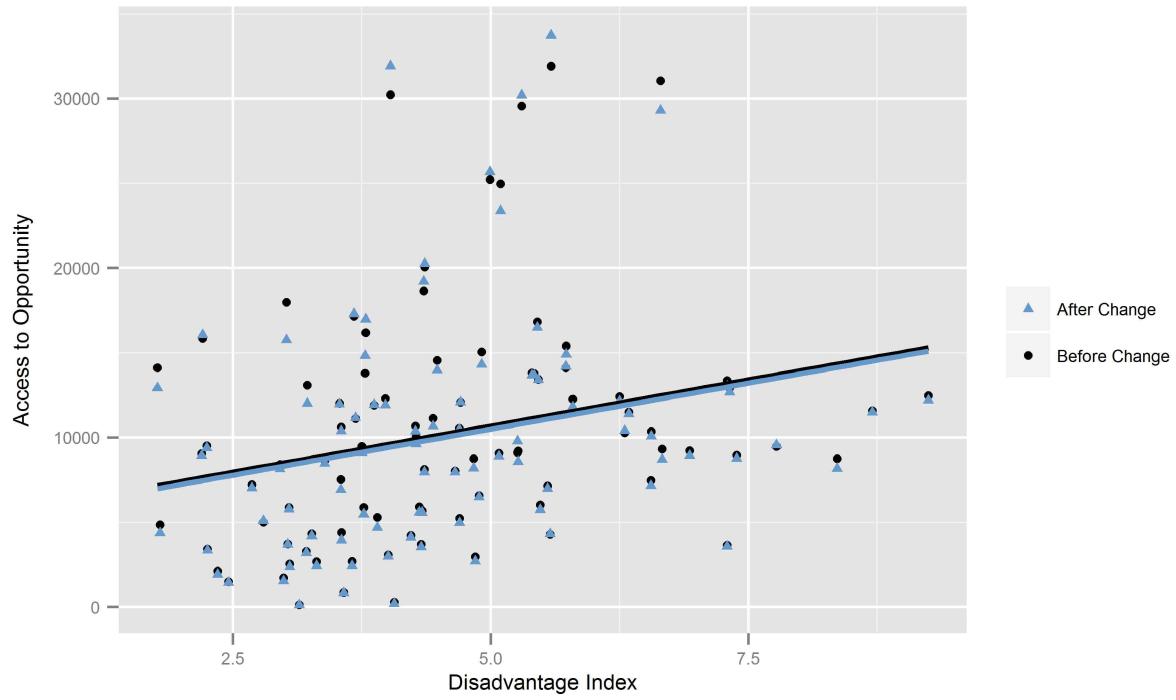


Figure 32. Access to Health Care / Social Services: Before and After Network Change

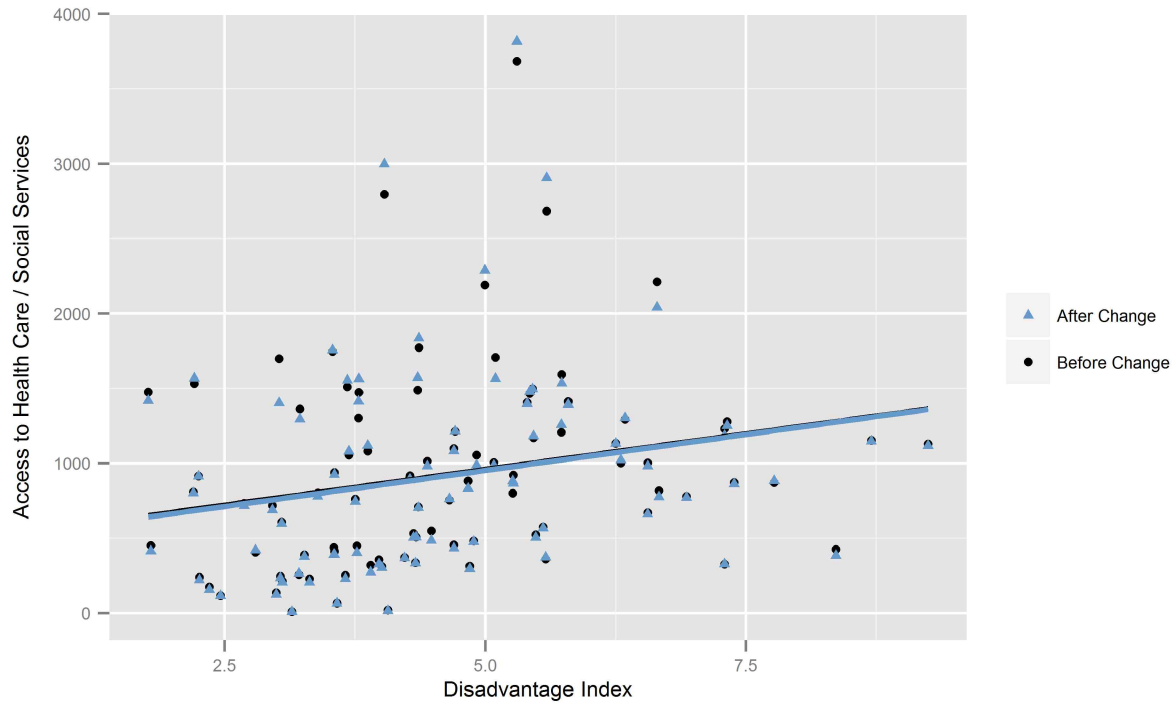


Figure 33. Access to Retail / Shopping: Before and After Network Change

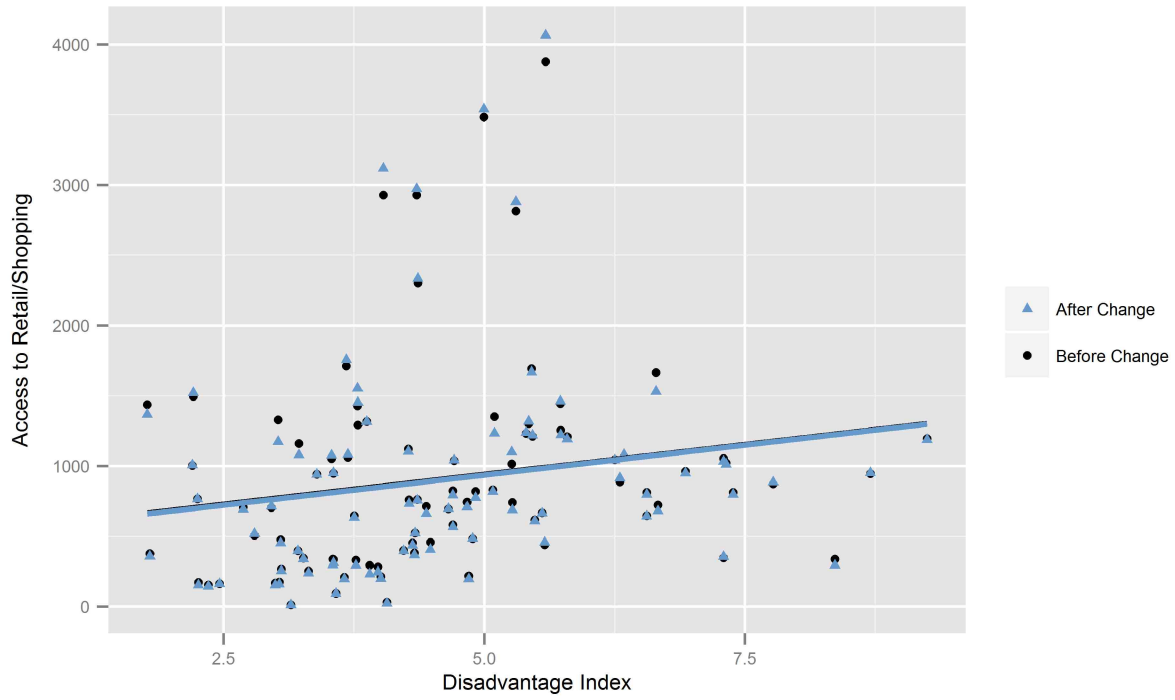


Figure 34. Access to Education: Before and After Network Change

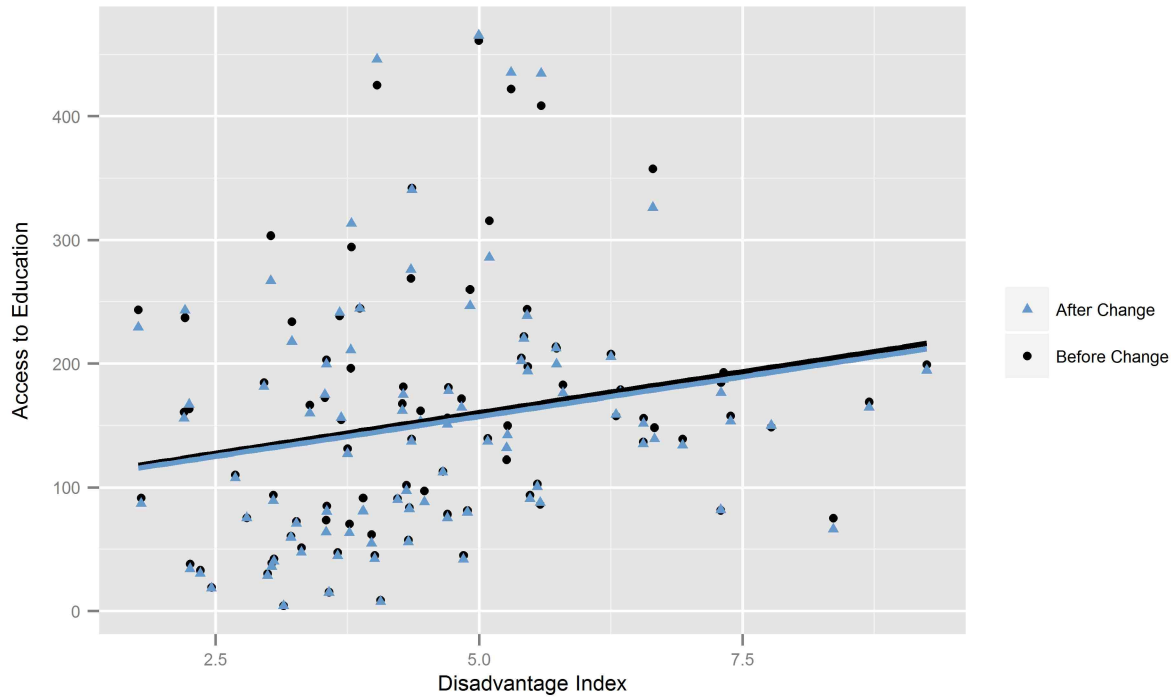


Figure 35. Access to Entertainment: Before and After Network Change

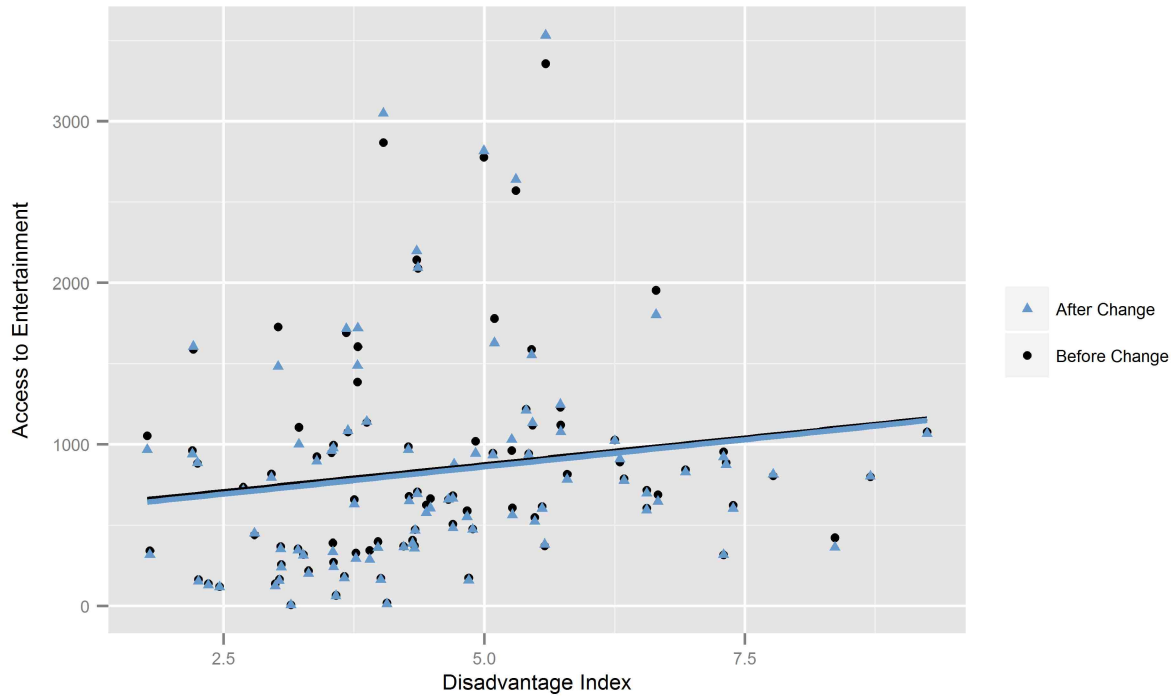


Figure 36. Access to Jobs (High School or Less): Before and After Network Change

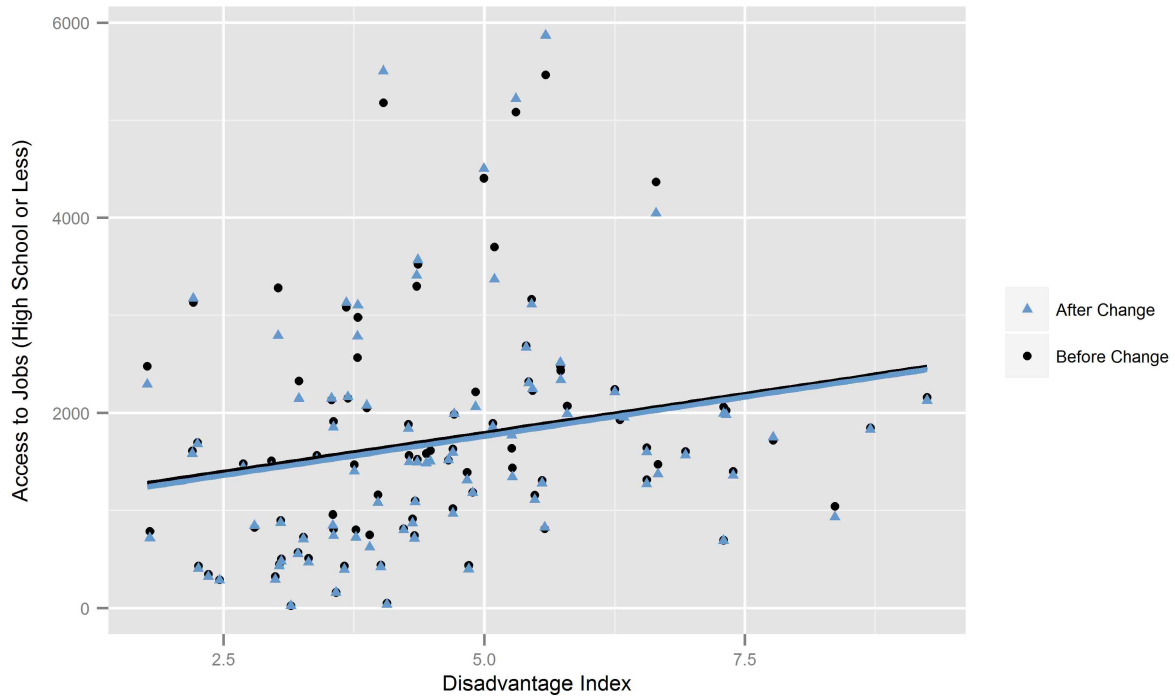
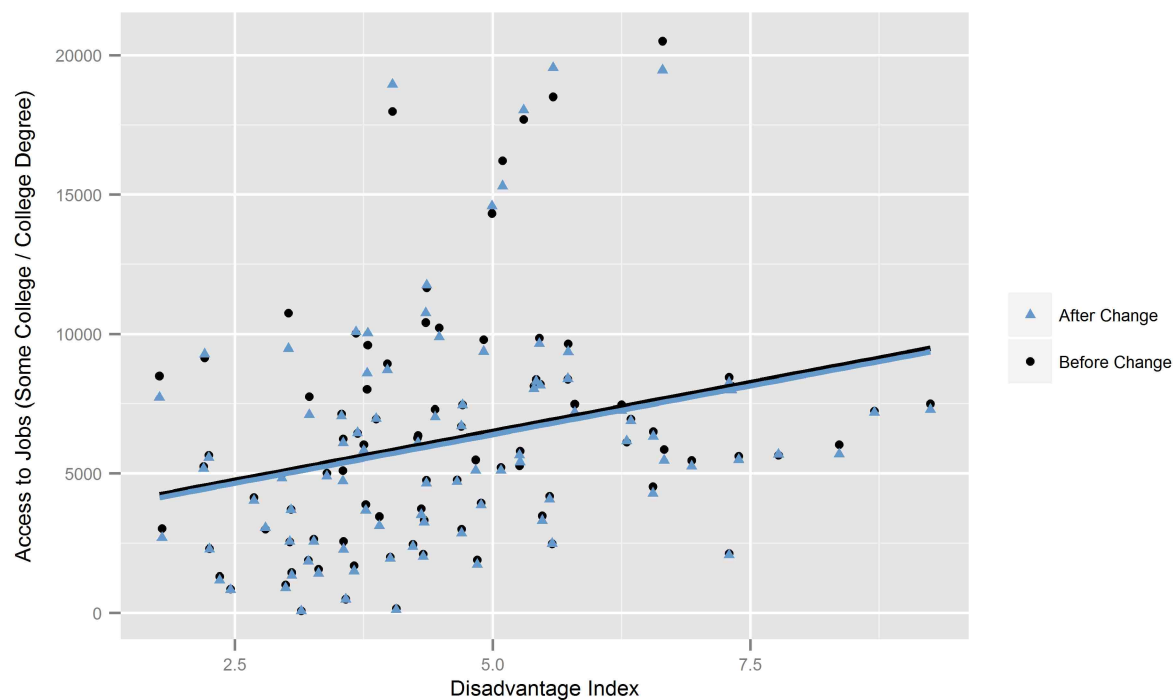


Figure 37. Access to Jobs (Some College / College Degree): Before and After Network Change



While the overall changes represent a minor decrease in accessibility, it is interesting to note that some block groups experienced *increases* in accessibility (where light blue triangles appear above dark blue dots). Restructures and other minor alterations that accompanied the service reductions likely resulted in slight increases in service for pockets of the sub-area.

Figure 38 shows the change to overall access to opportunity; access to other categories follows the same general pattern. Figure 39 combines increases and decreases in accessibility with the disadvantage index. As before, deeper purples indicate those areas where the least advantaged experienced the greatest decreases in accessibility.

Variations on the same theme emerge in the maps. The northeast portion of the study area (southwest Redmond / Overlake) exhibits the greatest disadvantage and the greatest losses in accessibility due to the service change. Block groups in the central and southwest (Factoria)

portions of the study area show the same result. The northwest portion of the study area exhibits less disadvantage and moderate losses in accessibility.

Figure 38. Secondary Study Area Change in Access to Opportunity, Morning Peak

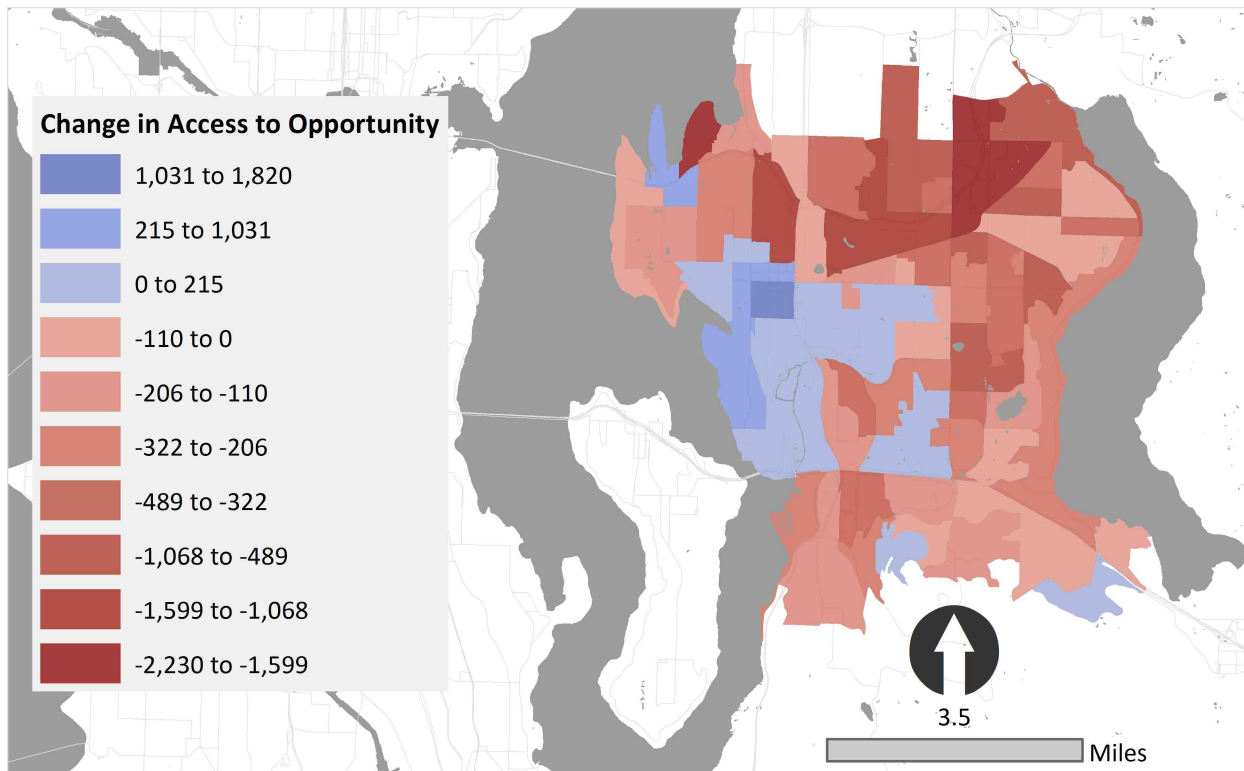
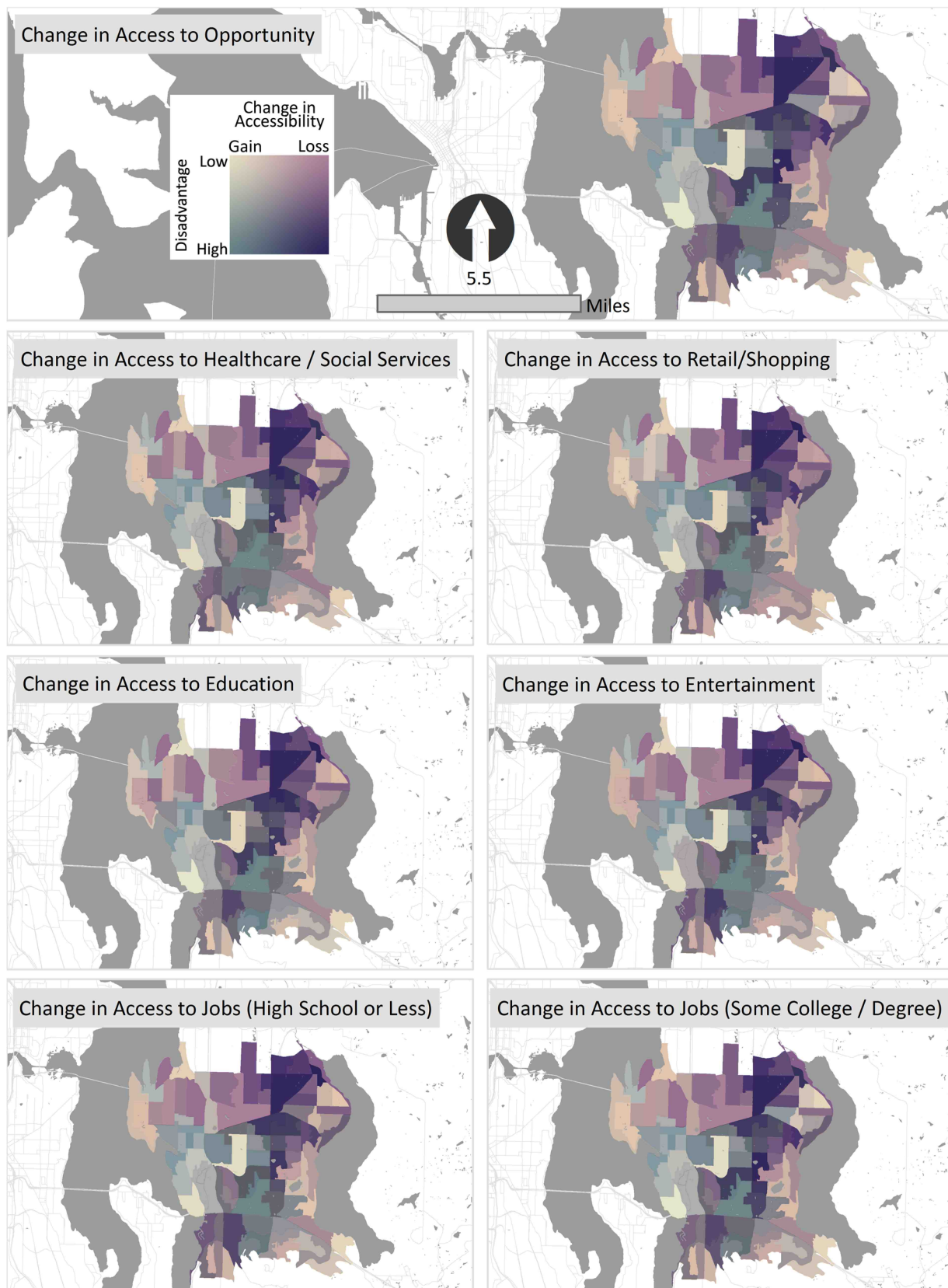


Figure 39. Transit Disadvantage: Secondary Study Area



5 Discussion

5.1 Corridor Scoring

This section will first discuss the effects of the revised corridor scoring methodology. The different methods will then be compared, followed by a discussion of costs and benefits associated with the methodological changes. Before diving in, recall that “initial” service levels are set by Step 1 of the corridor analysis and that “target” service levels are set in Step 2.

5.1.1 Effects of the Scoring Method Revision

The Service Guidelines process is focused on generating a set of investment priorities and attempts to answer the question: “Where in the network should investments be made?”

Therefore, the revised methodology should be examined in terms of the effect it would have on investment priorities. Recall that the social equity score accounts for only 25% of the total corridor score; a corridor’s total score determines the amount of service it should have. By policy, various levels of service are keyed to these total scores, as shown in Table 8.

Table 8. Corridor Scores and Headways

Initial service level (headway)	Points Required		
	Peak	Off-Peak	Night
15 min	19-40	25-40	--
30 min	10-18	10-24	19-40
60 min	0-9	0-9	0-18

Source: King County Metro (2013a)

All other things being equal, the amount of service a particular corridor *should* have will not be affected unless the change in the social equity scoring methodology produces a change in the *total* score that is sufficient to move the corridor from one level of service shown in Table 8 to another. Table 9 lists the 39 corridors (36 for Method 1 and 27 for Method 2) for which a change in the social equity score (listed separately for each scoring method) resulted in the total

score crossing one of these thresholds and the resulting change(s) to the corridor's initial service level settings (in generalized terms).

Table 9. Changes in Initial Service Levels due to Methodology Change

ID	Major Route	Original Total Score	Method 1		Method 2	
			Total Score	Initial Service Level Changes	Total Score	Initial Service Level Changes
1	128	14	16	None	19	Increase in peak and night
4	181	17	20	Increase in peak and night	22	Increase in peak and night
7	248	21	14	Decrease in all periods	11	Decrease in peak and night
9	40	22	25	Increase in off-peak	22	None
14	271	25	21	Decrease in off-peak	22	Decrease in off-peak
16	240	23	18	Decrease in peak and night	17	Decrease in peak and night
21	10	25	23	Decrease in off-peak	20	Decrease in off-peak
26	33	18	21	Increase in peak and night	19	Increase in peak and night
29	226	6	12	Increase in peak and off-peak	12	Increase in peak and off-peak
37	164	16	19	Increase in peak and night	21	Increase in peak and night
39	21	29	24	Decrease in off-peak	24	Decrease in off-peak
43	234	9	11	Increase in peak and off-peak	9	None
44	331	9	12	Increase in peak and off-peak	10	Increase in peak and off-peak
45	372E	15	19	Increase in peak and night	17	None
46	935	9	12	Increase in peak and off-peak	9	None
48	166	19	16	Decrease in peak and night	18	Decrease in peak and night
49	168	9	15	Increase in peak and off-peak	16	Increase in peak and off-peak
51	150	26	24	Decrease in off-peak	26	None
57	65	17	20	Increase in peak and night	17	None
60	2	25	24	Decrease in off-peak	23	Decrease in off-peak
61	24	23	25	Increase in off-peak	23	None
62	202/204	9	10	Increase in peak and off-peak	9	None
65	347	8	11	Increase in peak and off-peak	9	None
66	48	29	23	Decrease in off-peak	22	Decrease in off-peak
69	16	24	27	Increase in off-peak	25	Increase in off-peak
70	68	19	17	Decrease in peak and night	14	Decrease in peak and night
72	226	26	19	Decrease in off-peak	17	Decrease in all periods
74	917	10	9	Decrease in peak and off-peak	10	None
75	2/13	25	23	Decrease in off-peak	21	Decrease in off-peak
76	3/4	25	24	Decrease in off-peak	22	Decrease in off-peak
82	224	12	9	Decrease in peak and off-peak	7	Decrease in peak and off-peak
86	106	25	24	Decrease in off-peak	25	None
92	30	21	20	None	18	Decrease in peak and night
95	330	13	19	Increase in peak and night	19	Increase in peak and night
98	236	9	11	Increase in peak and off-peak	9	None
103	187	9	11	Increase in peak and off-peak	13	Increase in peak and off-peak
106	271	27	24	Decrease in off-peak	22	Decrease in off-peak
107	25	23	20	None	18	Decrease in peak and night
112	125	18	19	Increase in peak and night	19	Increase in peak and night

Sources: King County Metro (2014a); author's analysis

The next step in determining the effects on investment priorities involves comparing these *initial* service levels to two additional data points: the *target* service levels set in step two of the corridor analysis, and the service that is currently provided. Real changes to headways will occur only if the initial service levels *exceed* the existing target service levels and only if the target service levels *exceed* the service currently provided. Setting the target service levels in step two of the corridor analysis takes into account current demand (bus loads), cost recovery, and for night service, a determination of whether or not the route is the primary connection between regional growth centers. Once the target service levels are determined, a comparison to the current service is made. If the target service levels *exceed* the service currently provided, the corridor is below its target service level and will be targeted for investment. Based on these factors, Table 10 shows the five corridors that would be targeted for additional investment beyond that identified in the 2014 analysis if the revised social equity scoring methodology were used.

Table 10. Additional Investments Under Revised Methodology

ID	Between	And	Major Route	Method 1	Method 2
				Period receiving investment	Period receiving investment
4	Auburn	Federal Way	181	Peak	Peak
46	Kenmore	Totem Lake	935	Off-peak	None
61	Magnolia	Seattle CBD	24	Off-peak	None
95	Shoreline CC	Lake City	330	Peak and night	Peak and night
103	Twin Lakes	Federal Way	187	Off-peak	Off-peak

Sources: King County Metro (2014a); author's analysis

As shown, only 4.5% of corridors (5 of 112) would receive more investment using Method 1; the number drops to only 2.7% (3 of 112) using Method 2.

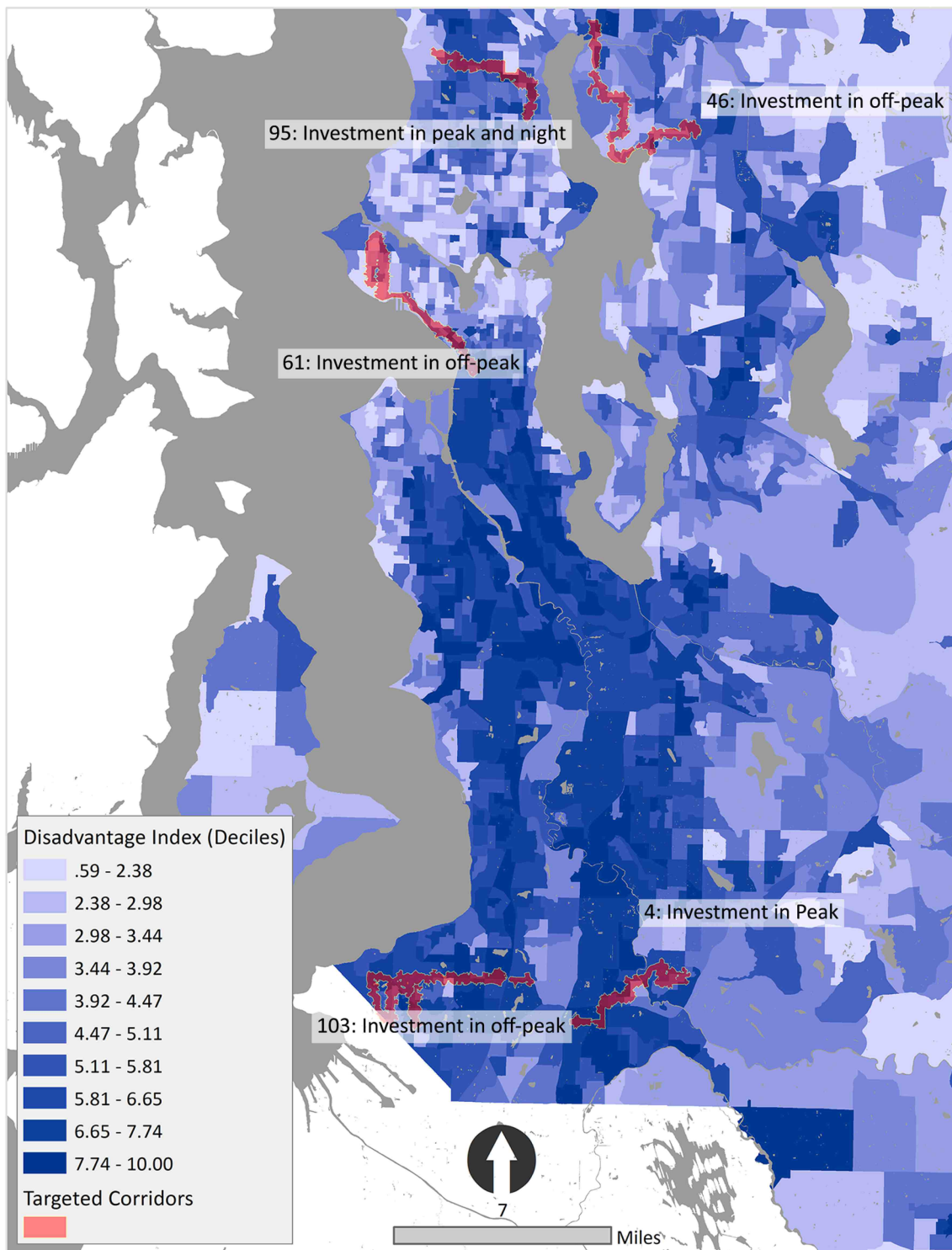
The other question to consider is how changes in corridors' social equity scores, particularly those that *declined*, might affect their potential to have service reduced. When reducing service,

the Guidelines focus on route performance. In simplified terms, the bottom 25% of performers are targeted first, and only in the third sub-criteria would a change in a corridor's social equity score possibly affect its likelihood of being targeted for reductions: if a low-performing route operated on a corridor whose current service *exceeded* its target service level, it could be targeted for reduction (King County Metro 2013a). Due to the complexity of the corridor analysis, it is extremely difficult to determine if hypothetical reductions in corridor scores would result in decreases in target service levels. Changes in *initial* service levels, on the other hand, *are* possible to determine, as presented in Section 4.2. Potential *increases* in target service levels are also possible to determine, as a corridor's target service level *cannot*, by policy, be below its initial service level; if a corridor's initial service level increased, its target service level must also increase. If a corridor's initial service level decreased as a result of an alternative scoring method, its target service level may not necessarily decrease. Despite these difficulties, it is worth noting that only one route (route 30, corridor 92) whose *initial* service level decreased as a result of either of the revised scoring methodologies was targeted for reduction in Metro's September 2014 cuts.

It is clear that from a system-wide perspective, the changes in investment priorities resulting from the revised social equity scoring methodology are slight. However, the locations of the corridors that would be targeted for additional investment warrant examination. Figure 40 depicts the spatial relationships of the corridors that would be targeted for additional investment using the revised methodology in relation to the Disadvantage Index. Corridors 4 and 103 in the south serve areas of relatively high disadvantage. Corridor 95 in the north similarly serves disadvantaged areas. Corridor 46 on the east side serves mixed areas, while corridor 61, which serves downtown Seattle, traverses areas of relatively low disadvantage. Each of these corridors

touches areas in the worst decile of disadvantage. This may indicate that from a Rawlsian perspective, the change in the social equity scoring methodology produces a just result.

Figure 40. Corridors Receiving Additional Investment



5.1.2 Comparisons of Methods

Recall from Section 2 that the current Guidelines process uses boardings data to determine each corridor's social equity score. This has the effect of measuring actual transit *use*, but social equity analysis is concerned with what is *possible* (Martens and Golub 2011); other barriers may be preventing potential disadvantaged riders from accessing Metro's service. That need not mean Metro should not provide the service, for it is the intent of the social equity score to provide service to those who need it. Instead, if boardings data suggested riders are *not* accessing the service at levels Metro would otherwise suspect they should, investigation into the reasons why would be warranted. Boardings data also reflects the *productivity* of routes, which is separately considered within the Guidelines process; an ideal social equity score would represent social equity goals and nothing else.

The area-based weighting method used in this paper, however, is not without its limitations. In the context of the corridors' purpose of connecting people and places, it has the somewhat undesirable effect of favoring like-to-like connections. For instance, a corridor connecting a low-income residential area to a more affluent central business district would receive a lower social equity score than a corridor connecting that residential area to another low-income neighborhood – a connection few would likely use. Therefore, the use of boardings data from *inbound* trips (typically *toward* jobs centers) may, in the end, be a reasonable method to determine the characteristics of the population the corridor serves and, thereby, its social equity score. However, as previously noted, the method as it exists in the Guidelines prevents some disadvantaged populations from “counting” toward the social equity score; it excludes from consideration any census tract that is below the county-wide average in terms of the proportion of minorities and low-income residents living there. A potential solution to this problem may

involve altering the binary “low-income” or “not low-income” (and “minority” or “not minority”) nature of the analytic framework to instead use two continuous-scale variables:

- the ratio of low-income to non-low-income population (and, separately, minority to non-minority population) in each census tract, and
- the ratio of low-income to non-low-income boardings (and, separately, minority to non-minority boardings) in each corridor.

For instance, a corridor with 1,000 boardings occurring in a census tract with 20% of the population classified as low-income would have 200 boardings classified as low-income boardings. A ratio of low-income to non-low-income boardings for the entire corridor could then be computed. The computation of each corridor’s ratio could proceed step-wise, resulting in a range of ratios that, for example, could be grouped into 6-quantiles to determine each corridor’s social equity score (from 0 to 5 each for low-income and minority).¹⁸ However, the discussion thus far indicates that the changes in overall investment priorities produced by relatively minor changes in processes may not justify even the small increase in complexity over the current process that this revised process entails. Further exploration is warranted.

5.1.3 Costs and Benefits of Changes to Scoring Methodologies

The discussion to this point has been quite complex; I have attempted to describe the corridor analysis as clearly as possible while also including the detail necessary to understand the inner workings of the Service Guidelines process. The complexity of the Service Guidelines is, I believe, a significant drawback for two major reasons: it increases system overhead and it harms meaningful public participation by putting it out of reach for most people.

¹⁸ This particular framework does not address corridors defined by dial-a-ride (DART) service for which no boardings data is collected. Currently, these corridors’ social equity scores are determined by the ratio of the number of the corridor’s physical bus stops within low-income tracts to the number not in low-income tracts. If this ratio is above the system-wide average, the corridor receives social equity points. This method could continue to be used for DART service even if the revised framework described above were used for typical fixed-route service.

The ability of the community writ-large to engage in critiques of the Service Guidelines, or even to understand their complexity, is questionable. The Regional Transit Task Force recommended, and the King County Council passed, a set of policies that constitute a “black box;” Metro employees and the Guidelines process, no matter how much data and how many reports are published, are firmly in place behind the Wizard of Oz’ curtain. I do not mean to suggest that deceit is in play, but rather that the policy is of such complexity that it is *just* sufficiently understood by those responsible for its implementation. Furthermore, such computationally-intensive processes and the complexity of the underlying data systems required to run the analyses inevitably produce errors.¹⁹ This does not mean complex processes cannot be worthwhile, but rather that they must be evaluated in terms of how well they advance the goals being pursued. At a recent meeting of a Metro sounding board composed of community members, one citizen became flustered and confused when the Service Guidelines were explained and threatened to quit. Though this person was eventually persuaded to remain with the board (Day 2015), the event demonstrates the ways in which meaningful public participation, which is so crucial to social equity (Beatley 1988, Federal Transit Administration 1995, Levinson 2002, Lucy 1988), can be undercut when citizens cannot understand the mechanisms by which decisions are made. Since the Guidelines’ inception, no funds have been available to fill the investment priorities produced by the Guidelines analysis. This fact alone makes it difficult to justify the resource expenditures required to conduct the analysis for the past four years. It also makes it difficult to determine how well the Guidelines would advance social equity goals in an environment of growing resources. Given that the first two investment priorities (reduce crowding and improve

¹⁹ See, for example, King County Metro (2014a) references to data errors.

reliability) are not directly associated with the corridor analysis, and also that social equity accounts for only 25% of the total corridor score, it seems that the social equity score's ability to garner investment for areas of high disadvantage is rather limited. If this is true, then perhaps Metro should pursue social equity in other ways, redirecting resources from more quantitative methods to qualitative analysis and richer community engagement. On the other hand, the Guidelines have been used in service restructures and to determine the service cuts slated for 2014 and 2015 (only one of which came to fruition). It is difficult to judge the degree of influence social equity scores had on these actions, but I would wager that considerations and analysis in support of Title VI requirements had more force.

This paper attempted to define an alternative methodology to better account for social equity in the corridor scoring process. However, as alluded to above, perhaps more comprehensive changes to the Service Guidelines are required, particularly if Metro wishes to take other disadvantaged groups into account. Increasing the clarity and transparency of processes, even if it requires a reduction in the degree to which hard data drives investments, could have a more tangible impact if not only because disadvantaged groups may *feel* more connected to the process.

5.2 The Use of a Composite Index

My attempt to simplify the corridor analysis process by combining factors of disadvantage into a composite index resulted in the homogenization of disadvantage and, ultimately, the masking of relationships between discrete socioeconomic factors and accessibility. Recall that no significant relationships between the composite index and transit accessibility were found. Splitting the index back into its component parts does, however, reveal significant relationships. Figures 41 through 43 depict the concentration of low-income, minority, and disabled populations in

Figure 41. Low-Income Populations

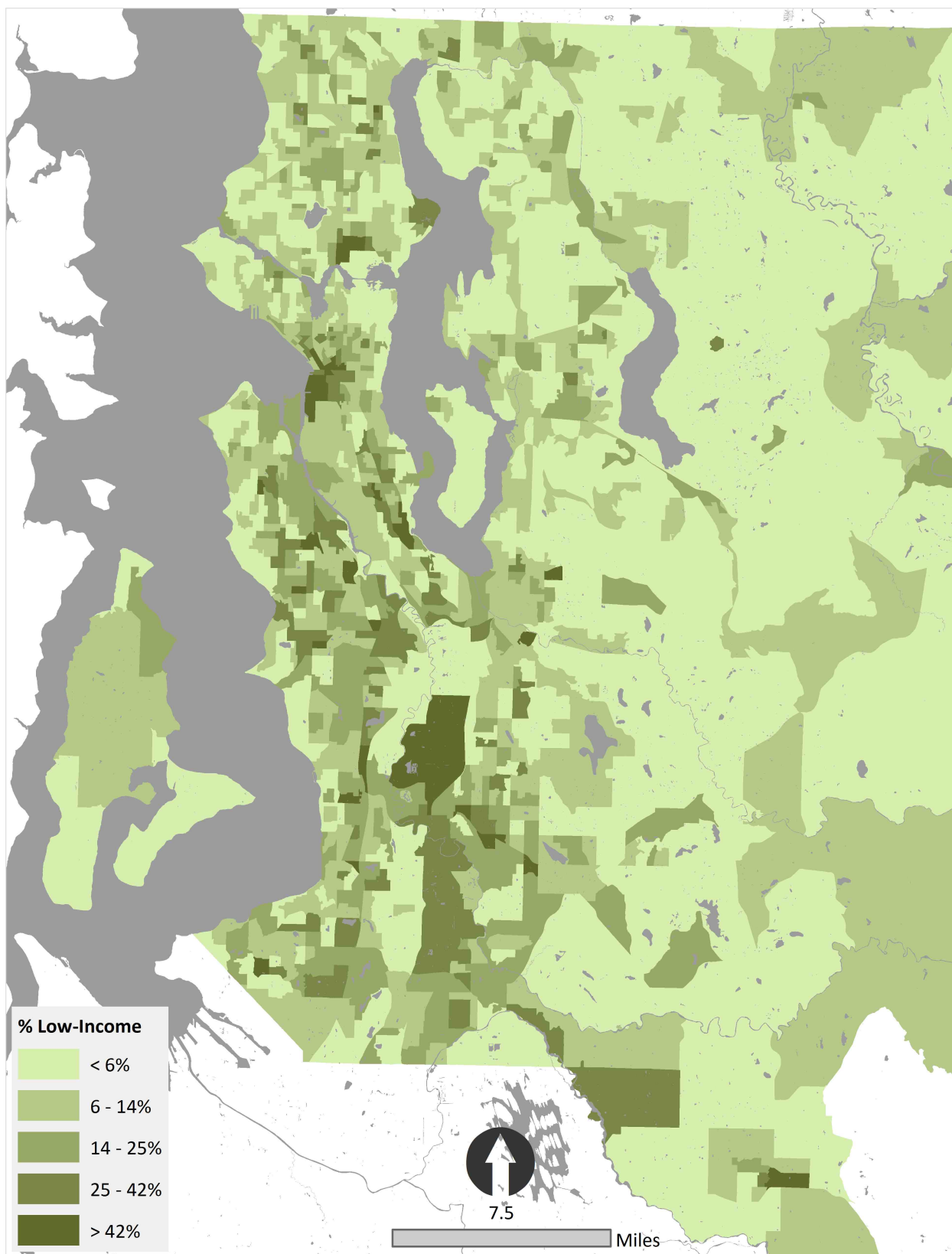


Figure 42. Minority Populations

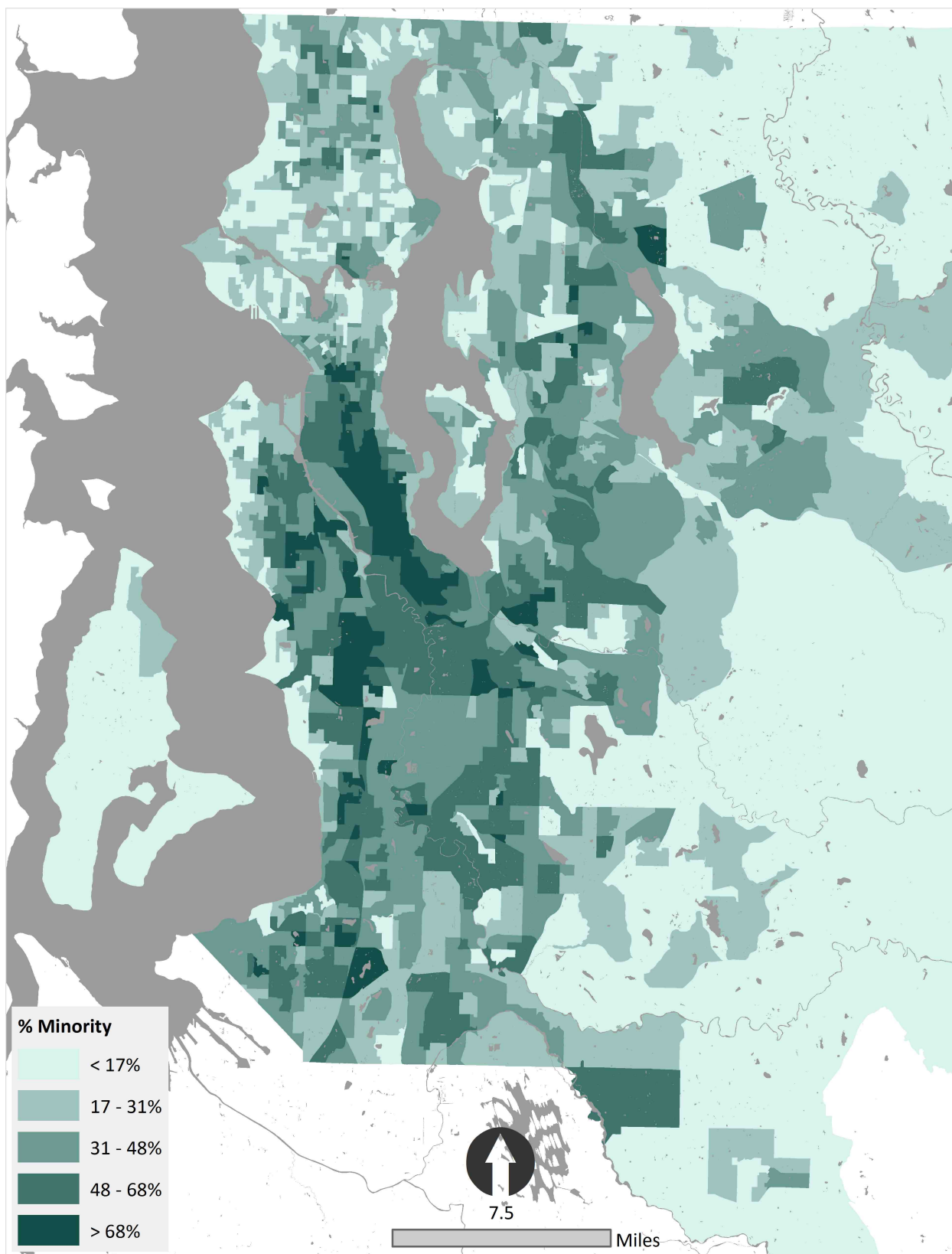
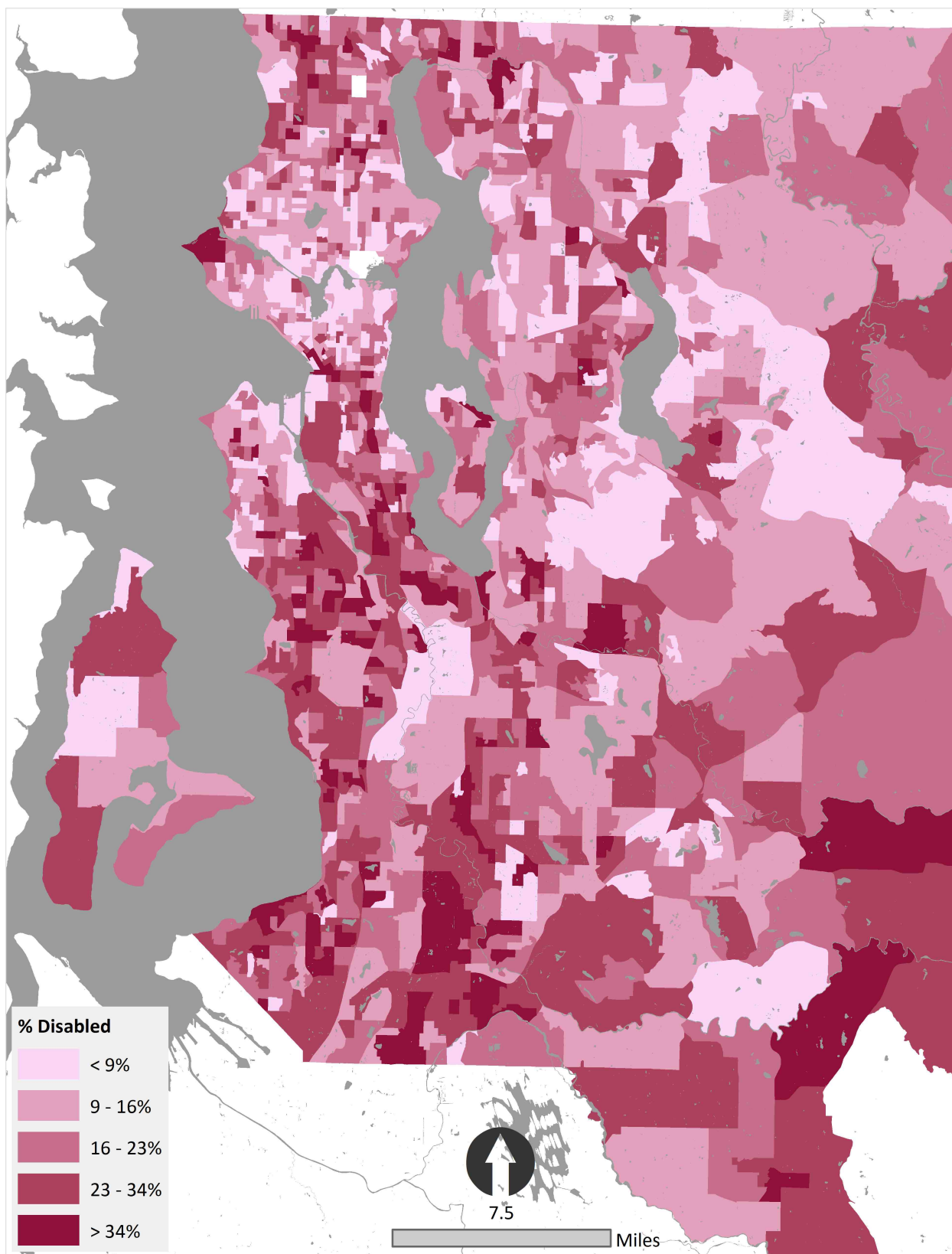


Figure 43. Disabled Populations



King County. Figure 44 reveals the relationships between access to opportunity (morning peak only) and these three socioeconomic factors. A strong positive relationship is revealed between access to opportunity and the proportion of census block group residents who are low-income. In general, the lower a resident's income, the better accessibility via transit they experience. However, no statistically significant relationship between access to opportunity and minority status is found. Finally, on the opposite end of the spectrum, a strong negative relationship exists between access to opportunity and disability; block groups with higher levels of disability experience lower levels of accessibility via transit.

Figure 45 presents bar plots of accessibility by decile. They largely tell the same story as the scatterplots. Finally, Figures 46 through 48 present maps similar to those in Section 4, combining the three factors (separately) with the measure of access to opportunity.

Statistical significance and strong relationships appeared in two out of the three categories. This indicates that disaggregated analyses can produce more knowledge about the relationships between access to opportunity and particular types of disadvantage than can an analysis that uses a composite index of disadvantage.

Figure 44. Access to Opportunity by Percent Low Income, Percent Minority, and Percent Disabled Morning Peak

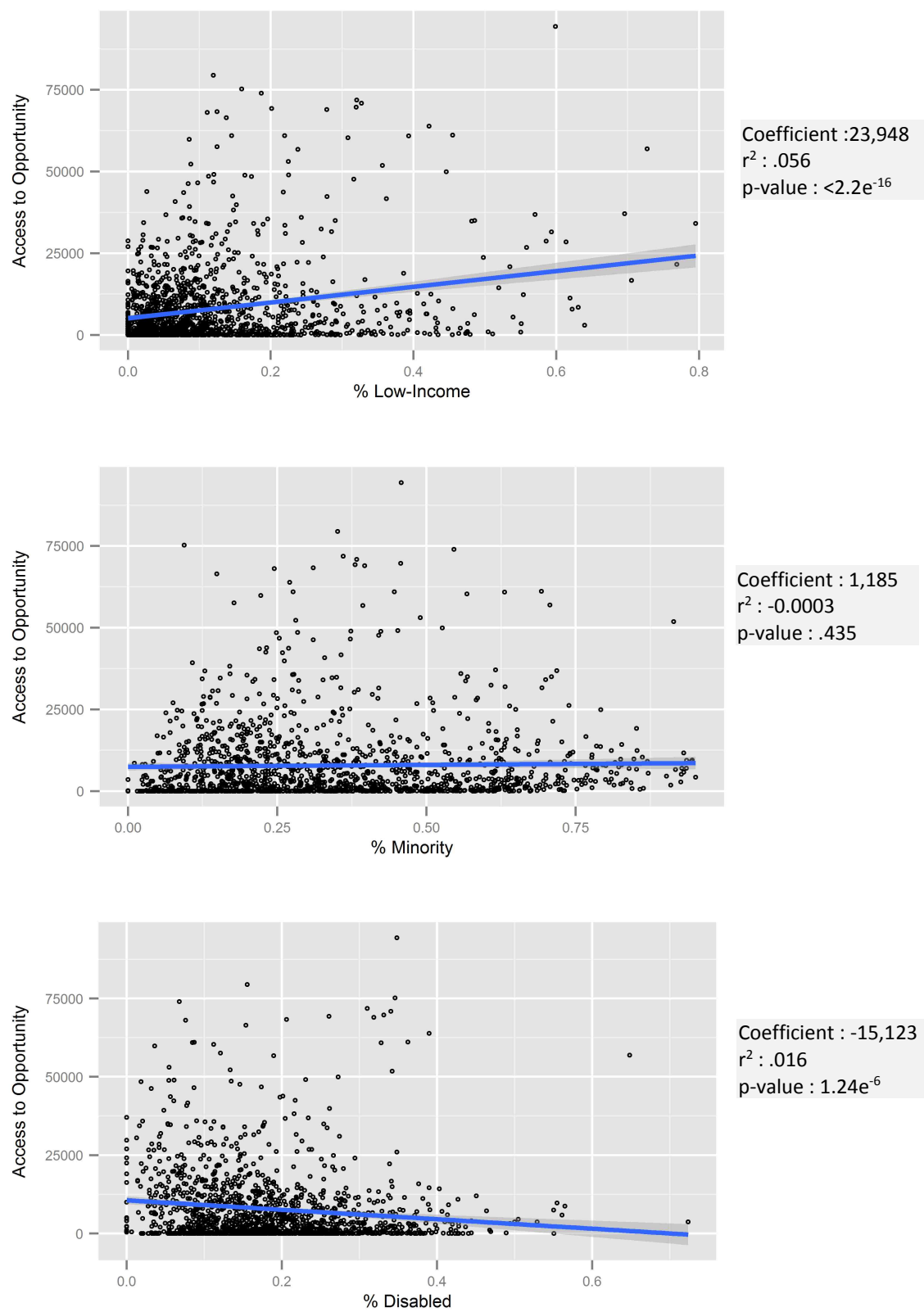


Figure 45. Average Access to Opportunity By Deciles, Morning Peak

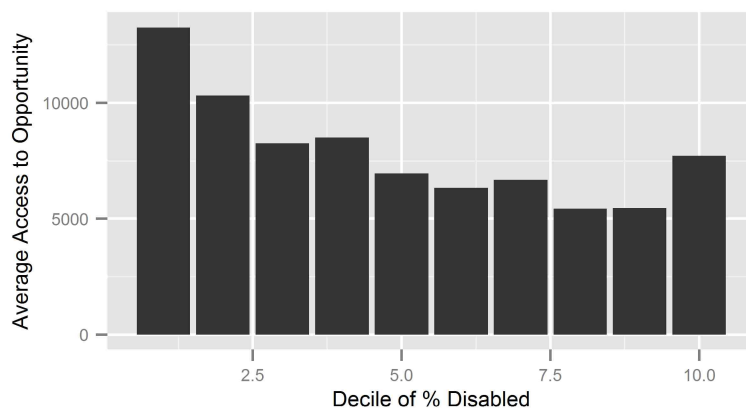
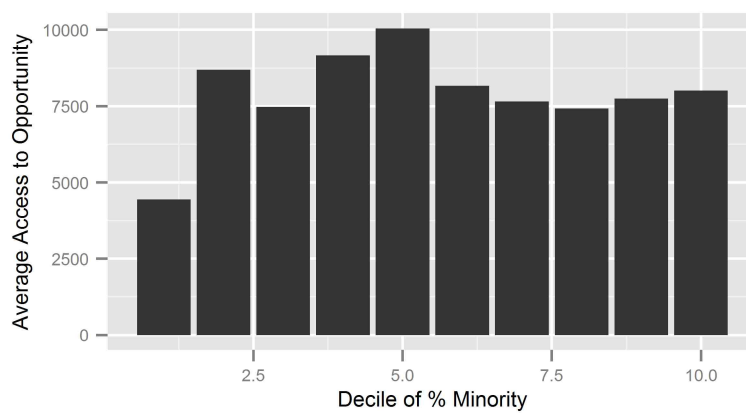
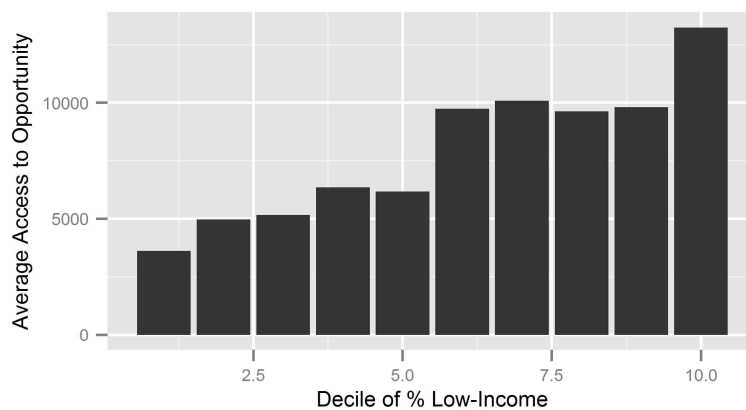


Figure 46. Transit Disadvantage for Low-Income Populations, Morning Peak



Figure 47. Transit Disadvantage for Minority Populations, Morning Peak



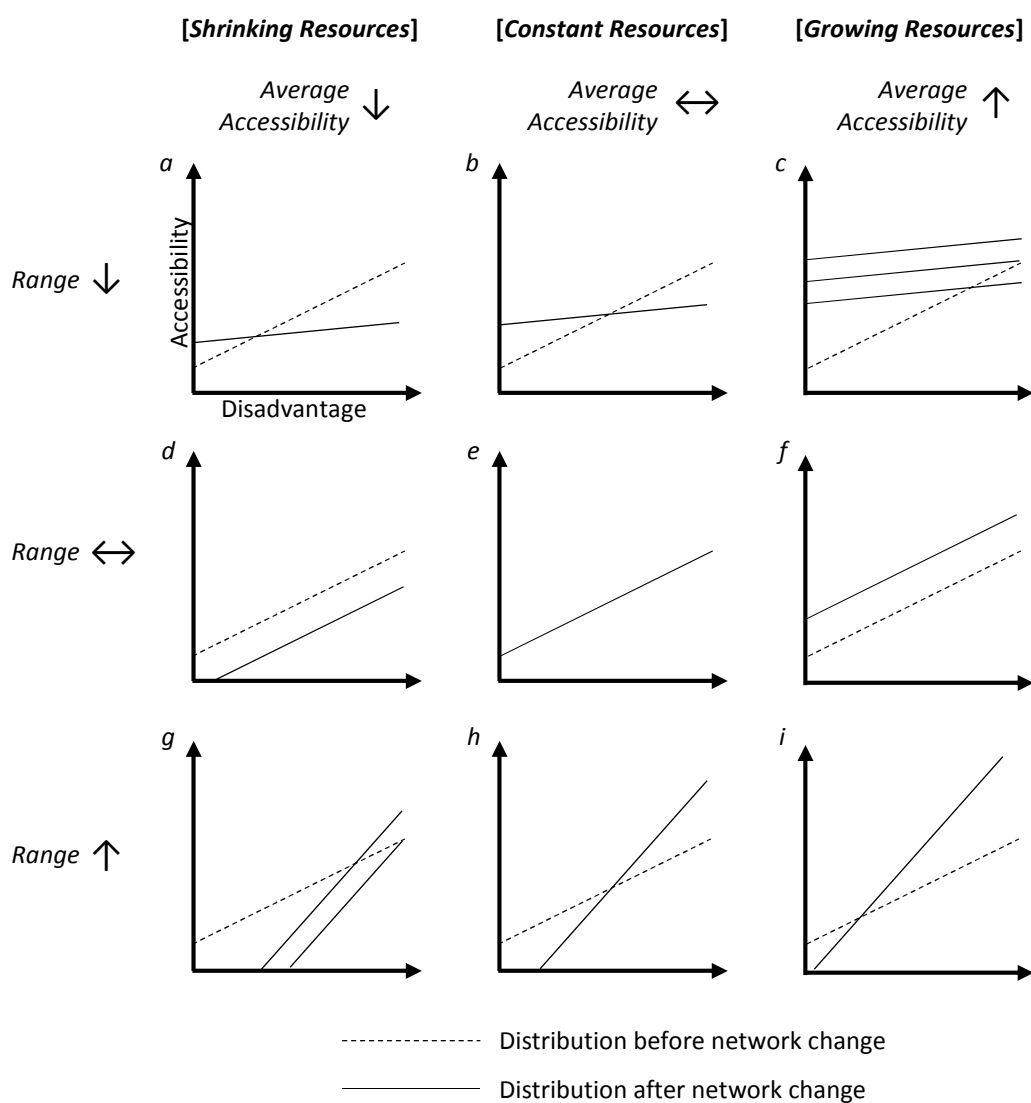
Figure 48. Transit Disadvantage for Disabled Populations, Morning Peak



5.3 Accessibility and Social Equity

The matrix of graphs depicting potential changes to average accessibility and the range between best and worst accessibilities is reproduced in Figure 49 (originally Figure 11).

Figure 49. Matrix of Changes in Distributions



Graphs *c* and *f* correspond to the maximax conception of equity of Martens, Golub, and Robinson (2012) (maximizing the average while observing a maximum range). However, the bottom solid line of graph *c* also represents a situation in which benefits are *decreased* for the least advantaged. Such an outcome would not uphold a strictly Rawlsian conception of equity.

Graphs that would pass the Rawlsian test (in which benefits accrue to the least advantaged) include graphs *c* (the top-most solid line), *f*, *g* (the top-most solid line), *h*, and *i*. Most of these, however, do not fit into the maximax conception of equity. How, then, are we to evaluate whether an outcome moves the needle closer to or farther away from equity? Furthermore, how can maximax assist in evaluating equity when overall resources *decrease*?

An examination of the tangible results of the before-and-after analysis of this paper's smaller study area may help. The scatterplots and descriptive statistics of the best-fit lines (from Section 4.3, which used the composite Disadvantage Index) are matched in Table 11 to the particular graphs they represent in the matrix above.

Table 11. Changes in Mean Access, Range, and Minimum Access Before/After Service Change

	Mean	Range	Corresponding Graph
Access to Opportunity	Decreased	Increased	<i>g</i>
Access to Health Care / Social Services	Decreased	Increased	<i>g</i>
Access to Retail/Shopping*	Decreased	Increased	<i>g</i>
Access to Education	Decreased	Increased	<i>g</i>
Access to Entertainment	Decreased	Increased	<i>g</i>
Access to Jobs (High School or Less)	Decreased	Increased	<i>g</i>
Access to Jobs (Some College / College Degree)	Decreased	Decreased	<i>a</i>

* Not statistically significant

All but the last category correspond to graph *g*, a reduction in average access and an increase in the range between best and worst. The last category, access to jobs (some college / college degree), corresponds to graph *a*, a reduction in average access and a decrease in the range. A reduction in service can only decrease average access, so this factor is disregarded for the present. Since maximax demands the observation of a maximum range between those with the best access and those with the worst access, an increase in the range at best represents movement away from the goal and at worst a violation thereof (if the maximum range set by policy is

exceeded). In this sense, the service change largely *harmed* social equity because the range between the best access and worst access increased.

The discussion can be enriched by examining what happened to the accessibility of the least advantaged block group in the smaller study area, as presented in Table 12.

Table 12. Changes in Access for the Least Advantaged Block Group (530330236042)

	Before	After	% Change	Average % Change	Maximum % Change
Access to Opportunity	12,489	12,191	-2.39	-1.78	+7.47
Access to Health Care / Social Services	1,130	1,118	-1.06	-0.76	+9.99
Access to Retail/Shopping	1,196	1,186	-0.84	-0.55	+12.35
Access to Education	199	195	-2.01	-1.94	+7.84
Access to Entertainment	1,079	1,068	-1.02	-1.53	+7.23
Access to Jobs (High School or Less)	2,162	2,128	-1.57	-1.68	+8.48
Access to Jobs (Some College / College Degree)	7,505	7,297	-2.77	-1.86	+7.27

In all cases, the access of the least advantaged group decreased. These results indicate that the change in access for this block group most closely resembles the *bottom* solid line of graph *g* in the matrix, as access for the least advantaged group decreased; access to jobs (some college / college degree) still corresponds to graph *a*.²⁰

Do the effects of the service change pass a Rawlsian conception of equity? To answer that question, the phrase “to the benefit of the least advantaged” needs to be modified for the present case. In a scenario involving service reductions, “benefit” may be conceived as the *least* decrease in access. However, recall from Section 4 that that some block groups experienced *increases* in access as a result of the service change. As shown in Table 12 (above), the least advantaged group clearly did not fare the best off. In fact, in five of the seven categories, the

²⁰ Note that the correlations to the graphs are meant to be rough approximations in the categorical sense; the exact slopes of the lines do not match.

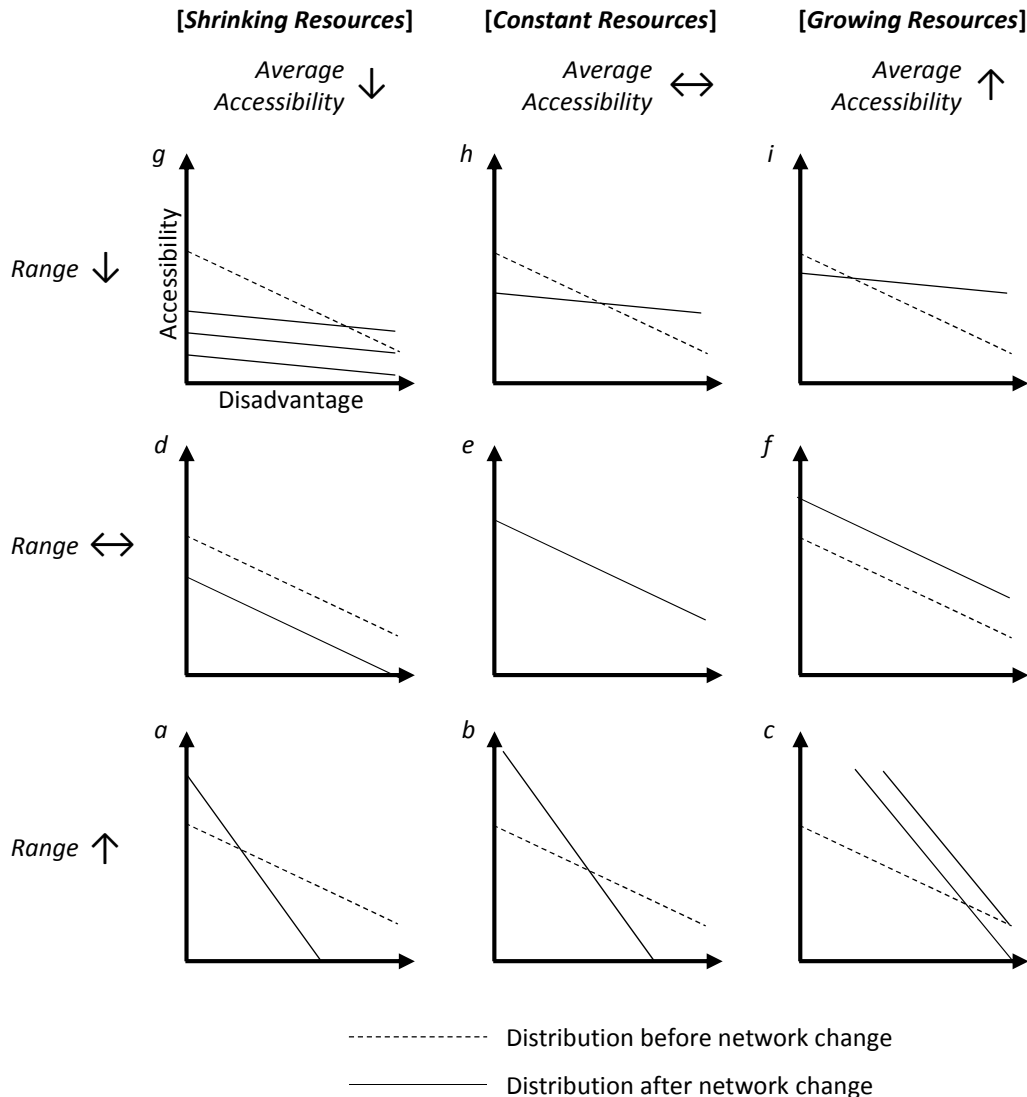
least advantaged group fared even worse than the average. Thus, the effects on accessibility of the service change in the study area cannot be said to have advanced equity in the Rawlsian conception.

To be fair, though, situations with upward-sloping lines are probably not what Martens, Golub, and Robinson had in mind. Instead, it seems more logical that they conceived of *downward-sloping* lines, representing negative relationships in which the least advantaged receive the least benefit. Recall from the discussion in the previous section that the correlation between accessibility and people with disabilities exhibits this type of negative relationship. In this case, it makes sense to constrain the range between the best and worst access, because the least advantaged experience the worst access; reducing disparity, or at least holding it steady, means that the least advantaged will never be worse off relative to the top than they are now.²¹ With that in mind, a new matrix of graphs is presented in Figure 50. In contrast to Figure 49, this set of graphs begin with *negative* relationship between disadvantage and accessibility; accessibility decreases as disadvantage decreases. Note that each graph's label (*a* through *i*) corresponds to the same-lettered graph in Figure 49 (positive relationships) in terms of the relative changes in accessibility among groups.

So, which graph represents the best outcome? The answer, of course, depends on one's perspective, and the reader is directed to Table 13, which describes the various equity impacts associated with each graph.

²¹ They could, however, be worse off in absolute terms if the average decreased across the board. This harkens back to Thatcher's famous quip in Parliament when she suggested that left liberals prefer the smallest income gap possible, even if it means everyone is worse off. This quintessentially defines the conflict between social equity and utilitarianism.

Figure 50. Matrix of Changes in Distributions (Negative Relationships)



Graphs *g*, *h*, and *i* (in both matrices) probably represent the fairest outcomes for shrinking resources, constant resources, and growing resources, respectively, at least from a Rawlsian perspective. This is because the least advantaged (most disadvantaged) experiences an increase in accessibility (in most cases). However, as mentioned in the table, portions of the population may lose transit access altogether, which could hinder the achievement of other social goals. These may include congestion reduction (with associated gains to economic efficiency) and reductions in air and noise pollution. Graphs *d*, *e*, and *f* may be considered fair by some, as all

people experience gains or losses in accessibility equally. They may not be considered fair under Rawls, as the least advantaged do not benefit relative to everyone else. Graphs *a*, *b*, and *c* represent situations in which the least advantaged experience either a disproportionately greater loss in benefit or a disproportionately lesser increase in benefit than the most advantaged. This clearly violates the Rawlsian conception of equity, but it may satisfy other conceptions of equity. Recall that a full evaluation of equity requires determinations of the distributions of both benefits and burdens; if those who are paying the most for transit service experience the best increases in accessibility (or least worst decreases), this may be considered fair.

For strict egalitarians, reducing the range between the best and worst access (graphs *a*, *b*, and *c* in the upward-sloping set and graphs *g*, *h*, and *i* in the downward-sloping set) may represent the best outcomes of transit network changes. These graphs represent movement toward equality in accessibility, the goal of egalitarians. Again, though, this discounts the distribution of burdens; the strictest of egalitarians would require that benefits *and* burdens all be equally distributed.

No matter which conception of equity one ascribes to, this framework and methodology at least provides a tool to evaluate the equity impacts of service changes. As stated before, the ultimate judge of the fairness (or equity) of the outcome is left to the observer.

Table 13. Service Change Examples and Equity Impacts

Graph	Example Service Changes	Equity Impact (positive correlation)	Equity Impact (negative correlation)
<i>a</i>	Service reduction spreading service more evenly, with a higher proportion of cuts occurring in disadvantaged areas (opposite of <i>g</i>);	Movement toward egalitarianism The least advantaged experience the largest loss of benefit, but the difference between the best and worst access has been reduced.	The least advantaged experience the largest loss of benefit; disparity increases.
<i>b</i>	Resource-neutral network restructure cutting service in the least advantaged areas to provide better service in the most advantaged areas (opposite of <i>h</i>)	Movement toward egalitarianism Those with other means of transport receive increased service to the detriment of those who rely on transit.	Disparity increases, and those with the most need may lose all service.
<i>c</i>	Network expansion with added service concentrated in most advantaged areas (opposite of <i>i</i>)	Movement toward egalitarianism The least advantaged may lose or gain benefit (marginally), but any gain will be less than that experienced by the most advantaged.	The least advantaged may lose or gain benefit (marginally), but any gain will be less than that experienced by the most advantaged.
<i>d</i>	Service reduction, with cuts occurring equally throughout the network	Some lose service altogether, but they likely have access to other means of transport; those who rely on transit may disproportionately suffer from the cuts.	Those who rely on transit may lose service altogether, suffering more relative to those with access to other means of transport.
<i>e</i>	Network restructure with no system-wide benefit or changes in relative access	No impact	No impact
<i>f</i>	Network expansion with additions being spread equally throughout the network	Access is increased across the board, enabling the achievement of better outcomes, but it is increased for people who likely have access to other means of transport to the same degree as those who do not.	
<i>g</i>	Service reduction with a higher proportion of cuts occurring in more advantaged areas; Restructure with a sacrifice in average access to provide better access to the least advantaged (opposite of <i>a</i>)	Those who need service most continue to receive it, but some may lose all service. However, those who lose service likely have access to other means of transport.	Movement toward egalitarianism The least advantaged may gain or lose access (marginally), and this loss will be less than that experienced by the most advantaged.
<i>h</i>	Resource-neutral restructure with cuts in more advantaged areas enabling better service to the least advantaged areas (opposite of <i>b</i>)	The least advantaged benefit most, but some may lose all service. Those who lose service likely have access to other means of transport.	Movement toward egalitarianism Those who rely on transit benefit more, while those with other means of transport lose access
<i>i</i>	Network expansion with added service concentrated in the least advantaged areas (opposite of <i>c</i>)	Benefits accruing to the least advantaged may exceed need (wasted capacity); others who could use service (potentially to achieve other goals, including congestion reduction and environmental benefits, may lose service.	Movement toward egalitarianism The least advantaged benefit greatly at little cost to the most advantaged, particularly if the most advantaged have access to other means of transport.

5.3.1 Using Disaggregated Index Factors

In light of the findings regarding the use of a composite index, it is briefly noted here that when socioeconomic factors are considered individually, new relationships emerge between these factors and changes in accessibility resulting from network alterations. Table 14 presents descriptive statistics of linear models of access to opportunity (morning peak period only) versus each of low-income, minority, and disabled populations.

Table 14. Relationships Between Socioeconomic Factors and Access to Opportunity, Before and After Service Change (Morning Peak)

		Coefficient	r ²	p-value	Least Advantaged Block Group		Average % Change	Max % Change
					Access to Opportunity	% Change		
Low-income	Before	23,995	.063	.009	12,489			
	After	24,792	.066	.008	12,191	-2.39		
Minority	Before	11,956	.077	.004	13,774			
	After	11,944	.074	.005	13,678	-0.70	-1.78	+7.47
Disabled	Before	2,541	.001	.763	8,764			
	After	1,858	.001	.828	8,174	-6.73		

For the low-income factor, the slope of the line is positive and increased even as mean access decreased after the service change; however, the block group with the highest proportion of low-income residents experienced a worse drop in access than average. For the minority factor, the slope slightly decreased, potentially indicating a decrease in equity, but the block group with the highest proportion of minorities experienced a drop in access to a lesser degree than the average; this was still not as positive an outcome as existed in the study area (represented in the far-right column). Disabled populations fared the worst, even though the relationship in the smaller study area is positive (unlike the county as a whole). The relationship between accessibility and disability weakened, but this result is not statistically significant. The block group with the

highest proportion of people with disabilities experienced a decrease in accessibility far below the average, indicating an inequitable outcome.

5.4 Impact to Functional Analyses

Accessibility analyses could potentially substitute for, or at the very least enrich, certain analyses performed for Title VI purposes. As this paper recommends against aggregating various measures of disadvantage, analyses separately comparing before-and-after accessibility levels for low-income and minority groups could form the basis of making determinations of disparate impacts and disproportionate burdens. Metro's current Title VI practice considers low-income and minority populations, consistent with federal requirements; analyses focusing on LEP and disabled populations could be performed as an adjunct. An illustrative Title VI analysis is performed on this paper's smaller study area (using access to opportunity in the morning peak period) with the following process:

1. Measurements of accessibility are taken for each census block group before and after the service change.
2. Differences in accessibility are computed and then averaged.
3. Block groups are split into two groups: those below the average change in accessibility and those above. Those below the average represent areas exhibiting a higher-than-average negative impact resulting from the service change.
4. Among block groups below the average, the ratios of minorities to non-minorities and of low-income to non-low-income populations are calculated.
5. Adapting Metro's current standard, if these ratios are greater than the countywide averages (or study area averages) by 10%, a disparate impact (minorities) and/or disproportionate burden (low-income) is said to have occurred.

The changes in accessibility by block group are shown in Figure 51; the mean change in accessibility values across the study area resulting from the service change is -181.43. The results of the sample Title VI analysis are presented in Table 15.

While this analysis meets Title VI requirements, other groups of concern are clearly left out. For instance, the ADA does not require this sort of analysis to be conducted for disabled groups.

However, it is completely possible to repeat the same steps for virtually any group, provided data exists.

Figure 51. Change in Access to Opportunity Following Service Change, by Block Group

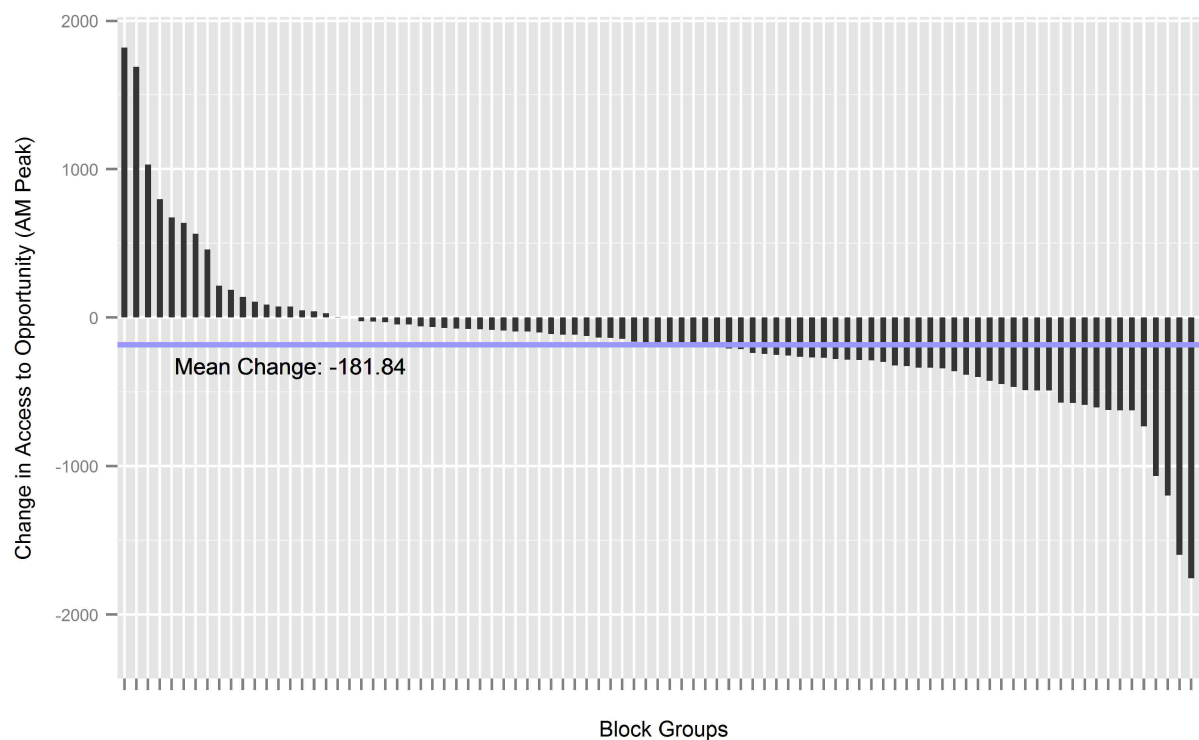


Table 15. Illustrative Title VI Analysis Results

	Study Area Total		Block Groups Experiencing Below-Average Change in Access		Disparate Impact / Disproportionate Burden?
	Residents	Ratio	Residents	Ratio	
Minorities	52,952	.647	24,417	.715	Yes (Threshold: .712)
Non-minorities	81,835		36,959		
Low-income	10,197	.082	4,570	.078	No (Threshold: .090)
Not low-income	124,180		58,540		

Source: US Census Bureau

Note: The total populations in each category are not equal due to the variations in the totals for whom each status is determined by the Census Bureau.

The results, which are largely only a demonstration of a technique, indicate that among those experiencing below-average losses in accessibility, the ratio of minorities to non-minorities is just above the threshold (which is set at 10% above the ratio of minorities to non-minorities for the entire study area); by the criteria set forth, a disparate impact occurred. Among those experiencing below-average losses, low-income populations formed a *lower* proportion compared to the study area as whole; no disproportionate burden resulted from the service change.

5.5 Causes of Low Accessibility Scores and the Land Use Nexus

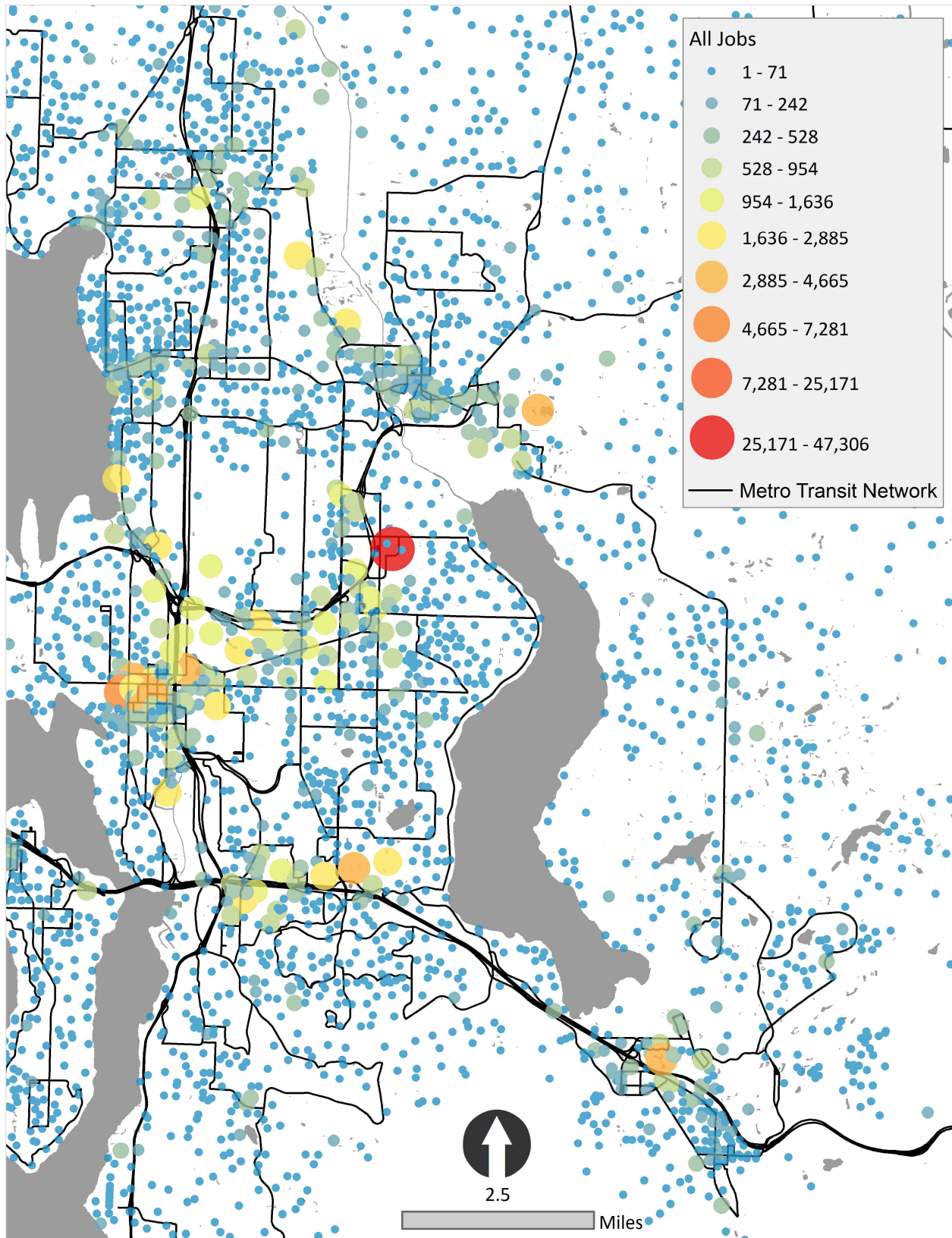
The low accessibility experienced in parts of King County results from a variety of factors; some of these are included within the analysis, and some are not. Additionally, Metro has control over only some of these factors. First and foremost, aspects of the transit network directly contribute or detract from accessibility. The spatial relationships of routes to jobs is perhaps the most critical factor. As shown in Figure 52, some routes simply do not pass through areas with high concentrations of jobs. The frequencies of these routes also affects accessibility scores. The methodology to compute accessibility takes a measurement for each minute of a two-hour block; accessibility scores are averaged across this entire time block, so areas with high-frequency routes will naturally have higher accessibility scores, all other things being equal. In this sense, the model actually measures the degree of opportunity to access opportunity via transit.

The speed of transit and the quality of transfers are two additional factors affecting accessibility scores. The model accounts for only some of the factors affecting speed. It implicitly includes the underlying road network (road classification) and transit priority treatments and explicitly includes stop spacing. It does not take congestion into consideration, instead relying solely on

scheduled travel times. Transfer times based on the published schedule are explicitly taken into account.

Lastly, land use, and specifically the number of jobs located within each individual travel shed, directly impacts accessibility scores. Areas with higher job densities will naturally score higher. The point of this discussion is to highlight that transit is only one component in increasing access to opportunity. Linking transit and land use planning to achieve higher, transit-supportive densities connected by fast, frequent transit would maximize access to opportunity via transit. The literature contains rich discussions of this concept.

Figure 52. Illustration of Spatial Relationships between Metro Transit Routes and Jobs



5.6 Methodology Limitations

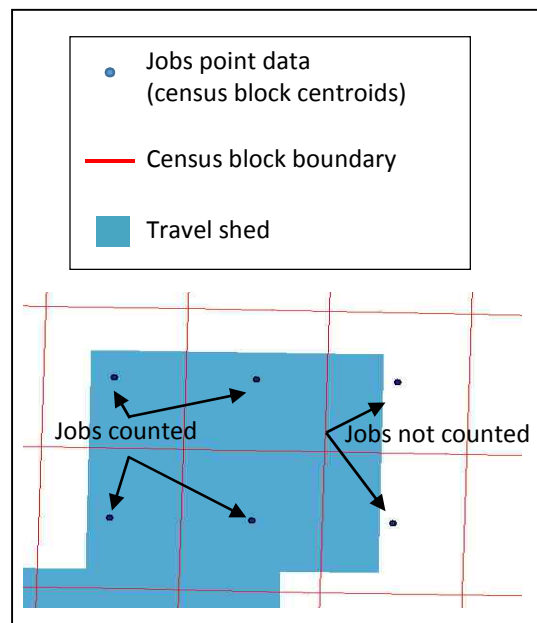
Scattered references to the limitations of the methodologies used in this paper have appeared in previous sections; this section attempts to assemble a comprehensive list.

The use of scheduled transit service, as opposed to some estimate of service as it actually exists (on average), was just discussed. Modifying the input GTFS feed to include some measure of variability per Popoks (2014), perhaps using a measure of congestion, could enrich the model and provide more realistic measures of accessibility. Additionally, while the model accounts for the *time* penalty for transfers, it does not incorporate a method to account for the increased *perceived burden* of each successive transfer that makes people unwilling to take trips that require them, per Popoks (2014).

Regarding the spatial modeling used in the methodology, the use of census block group centroids as travel start points represents a clear (but practical) limitation. Centroids may not be near the locations where people actually live. The larger the block group, the less valid the results. An additional limitation comprises the representation of jobs data as discrete points (conflated to census block

centroids) as opposed to either a smooth spreading throughout the census block or a representation of where the jobs *actually* exist. As shown in Figure 53, jobs in some census blocks may be invalidly included or excluded from any particular travel shed, depending on the exact locations of the jobs within the census block. This is simply the result of available data, which is, in and of itself, only an estimate that is subject to fuzzing by the Census Bureau.

Figure 53. Job Summing Limitation



The version of Hardin's accessibility tool used in this study has some limitations in terms of the walking component. For instance, it does not respect non-intersecting paths and does not account for elevation changes. Instead, it simply scales walking speed based on the distance from a path. The selection of starting points is, therefore, critical, as it is with any method of calculating accessibility. While analysis zones with smaller spatial extents and high path densities—as exist in dense areas—will present few problems, the methodology may produce lower-than-actual levels of accessibility for larger zones and/or those with fewer paths (as in eastern King County). This depends on the location of the travel starting point relative to paths *and* relative to transit access points.

Category limitations also exist. For instance, the data used for people with disabilities includes *all* disabilities, not just the ones that tend to make people transit-dependent. Additionally, the use of only 2-digit NAICS code granularity raises significant questions of validity for the analyses that use them; total jobs and the jobs breakdown by education level are relatively safe from this consideration. Still, many jobs that may not represent actual access to services are included in the calculations. Some may merely be office jobs, and some may be part of the export-oriented economy that does not provide local services. This likely results in the misrepresentation of the spatial distribution of access to each type of service (health care, education, etc.). Using a data set that more accurately reflects the jobs that represent each service type (and their locations) would produce more valid results.

Further to this, not all destinations are equal in terms of being rival or non-rival. For instance, someone may live in a location with excellent access to a large hospital (with many health care jobs). This facility may, though, be over capacity, depending on the demand for services it currently experiences. *Location* is only one factor contributing to the ability to realize access to

a service. On the other hand, a grocery store may not have the same level of rivalry, at least when food shortages are not an issue. In any case, the demand for certain services likely has some effect on the ability to access them, and demand will vary by location. This indicates that the methodology may overestimate accessibility to certain services in certain areas and that these differences would not be uniform across the study area.

Lastly, transit is only one means of transport. Any study examining transit accessibility will not account for total accessibility. A compact area with jobs and services within half a mile, but with no transit service, may not achieve high accessibility scores relative to other places, even though the land use of that area enables people to meet daily needs via non-motorized means. Although walking *is* included in the model, biking is not. The point here is that no minimum acceptable level of accessibility is established; while Martens, Golub, and Robinson (2012) would reject doing so, it seems reasonable to establish a minimum acceptable baseline of accessibility to at least some services. For example, if the least advantaged group cannot reasonably reach a grocery store by walking (or perhaps biking), Rawlsian equity would demand the provision of access to a grocery store for this group. This is especially true if the people in this area do not possess the means to relocate (Murray and Davis 2001). The provision of transit service to such an area is one, but not the only, means to achieve this end.

5.7 The Broader Picture

This paper has focused on fixed-route transit service, but this mode is only one of many available to transit agencies. Particularly in light of the Service Guidelines' formula to balance the often competing goals of productivity, geographic value, and social equity, social equity may lose out, and critical gaps in service may result. Furthermore, the pursuit of social equity goals solely with fixed-route service may prove so onerous and wasteful that it ceases to produce benefits that

outweigh its costs. This could produce situations in which resources are taken unnecessarily from other social programs. It is therefore critical to acknowledge that fixed-route service is not a silver bullet for transit inequities.

Metro has a variety of alternative services that, in some cases, are more efficient in their production of benefits than is fixed-route service (King County Metro 2015a). These services are often targeted in areas whose densities do not support efficient and cost-effective fixed-route service. They provide mobility options for many who have no other choice and are therefore a critical factor in evaluating how Metro works to achieve the social equity goals of the county. In short, the Service Guidelines, at least in their present form, provide an *incomplete* picture of the ways in which Metro incorporates social equity into its provision of transit service. This is true even for fixed-route service, as discussed in Section 2.3.1 (Service Planning).

These sorts of alternative service solutions, the development of which often follows an extensive outreach process and the formation of partnerships in the targeted communities (King County Metro 2012b), can serve to mitigate negative effects of service revisions. The most recent example involves the development of Community Shuttle Route 628, a contracted service operated by a local charity. This project was designed to help mitigate the reduction of service on route 208 and the deletion of routes 209 and 215 as part of the September 2014 cuts (King County Metro 2015b). It provides service to some of the more sparsely populated areas of county where fixed-route transit performed poorly.

Beyond transit service planning, the cost of using transit is yet another issue to take into consideration when evaluating the equity of the system. Previously, only the elderly, youth, and people with disabilities were eligible for reduced fares. However, in coordination with regional

transit agencies, Metro implemented a low-income fare in March, 2015. The revised fare structure enables people earning less than 200% of the federal poverty limit to ride for roughly half price (King County Metro 2015c). The change can be expected to price many low-income households into the transit market. It is reasonable to conclude this program will positively impact equity, at least in the Rawlsian conception, and it is important to keep this in mind when evaluating the fairness of the system.

Related to user fees, and bringing the conversation of equity full-circle, is the relative burden of the *costs* of the entire transit network and its support systems. Earlier, I explicitly excluded from consideration the burdens of the transit network, but acknowledged that an analysis of the distribution of the costs *and* benefits of the system is necessary to form a complete judgment of its fairness. At present, Metro is largely funded by the sales and use tax (54%); passenger fares form the second largest source (23%) (King County Metro 2015d). Sales taxes are typically viewed as regressive, meaning people with lower incomes pay a larger proportion of their incomes in the tax than the more affluent.²² Metro has virtually no control and little influence over its primary funding source, so the responsibility for implementing equitable (or fair) funding strategies likely rests with the broader population. As we have seen, solely determining the equity of the distribution of the benefits of transit is a problematic venture. The same is likely true for determining the equity of the distribution of the burdens. Combining the two to judge the equity of the entire system would be, to say the least, a monumental task.

²² Sales taxes may not always be regressive in application, depending on which basket of goods is exempt and the specific spending patterns of the population in question.

6 Conclusion

6.1 Summary of Findings

This paper attempted to answer the following questions:

- How should social equity be incorporated into the corridor analysis of Metro's Service Guidelines?
- To what degree does access to opportunity via transit vary by location and by relative disadvantage within King County?
- To what degree did a network change affect access to opportunity among groups of varying disadvantage, and how can these changes be evaluated in equity terms?

6.1.1 Equity and the Guidelines

This paper found that minor alterations to the social equity scoring methodology produce limited results, but that they may serve to marginally improve access for pockets of the most disadvantaged groups within King County. These benefits may not be worth the additional costs of altering the methodology. The corridor scoring methodology in the Service Guidelines is more than sufficient to meet the requirements of federal laws and regulations. However, the method in this paper, which directly measures the population, eliminates assumptions about why certain populations may or may not take the bus that are implicit in the current practice of incorporating boardings data into the social equity score. A final scoring methodology that provides the least advantaged group with a clear benefit in the final corridor score should be used if Rawlsian equity is to be advanced. Of the two methods presented, method 1 most closely adheres to this principle.

Additionally, the progressive ideology present in the region and reflected in the elected government demand that Metro go further than federal requirements. The conception of equity the King County Council adopted clearly gives Metro room to consider disparities in accessibility among other groups. However, this work need not necessarily be incorporated into

the Guidelines; the Guidelines are formal, strict, and require council action to change. Instead, the agency can advance equity goals (in accessibility terms) in service planning and community outreach processes.

Combining various factors of disadvantage into a single index was found to be problematic, as it masked relationships between accessibility and the component factors. Even in an index in which all factors are weighted equally, judgments of each factor's relative importance are implicit. For these reasons, each factor should be analyzed separately; this will reveal the most information about disparities in accessibility among groups and enable rectification to the highest degree. In this sense, the Guidelines (and federal regulations) get it right: minority and low-income populations are accounted for separately; this practice should continue, and future studies of equity should avoid composite measures of disadvantage. However, conducting analyses on a factor-by-factor basis does not eliminate the necessity of judging who matters more; these decisions must be made when deciding whom is to receive investments.

6.1.2 Disparities in Accessibility

As alluded to above, this study found no statistically significant relationship between accessibility provided by transit and the composite index of disadvantage. However, in secondary analyses, it did find a statistically significant and positive relationship between accessibility and low-income populations; census block groups with higher proportions of low-income households exhibit, on average, higher accessibility via transit. The study found no statistically significant relationship between accessibility and minority status. Census block groups with higher proportions of people with disabilities were found, on average, to exhibit lower levels of accessibility via fixed-route transit to a statistically significant degree.

Metro policy clearly states that low-income and minority populations deserve more transit service than their non-low-income and non-minority counterparts. If King County ascribes to the Rawlsian conception of equity, and I believe it does, the same ought to be true for people with disabilities. Particularly as Metro intends for fixed-route service to be the primary means of transit for people with disabilities, the consideration of disabled populations within the Guidelines (which governs fixed-route investments) is warranted. In the context of accessibility and access to opportunity, this is especially true given the requirements of ADA regulations to provide equal opportunity and access to people with disabilities. Additional evaluation of the degree to which people with disabilities are able (or unable) to access Metro's service would help address the evident disparities in accessibility. More emphasis in this area may also be called for in Metro's service planning processes.

Impacts to accessibility arising from reductions and revisions in Metro's service occurring in September 2014 were analyzed within the smaller study area comprising Bellevue and southwest Redmond. The least advantaged fared worse than the average in their accessibility to most categories of services and jobs and much worse compared to those who actually benefited from the service revisions. As with the larger study area, the disaggregation of socioeconomic factors revealed details of particular relationships. The service change produced overall positive outcomes for low-income populations, but did not significantly change accessibility for minority populations (on average). The service change deepened negative disparities in access among people with disabilities (although this relationship was not statistically significant).

6.1.3 A Framework for Equity Evaluation

Evidence of confusion about equity was found in the literature reviewed for this paper. Equity is not synonymous with equality; techniques evaluating the equality of distributions are

inapplicable when the focus is on equity. Evaluations of equity also require more than just raw data: they require a philosophical underpinning that must be explicitly stated before a determination of whether or not a situation is equitable can be made. Furthermore, the Rawlsian conception of equity, which is most likely dominant in left-liberal communities, must be understood to allow disparities among people. The fairness of these disparities can only be evaluated in broader contexts: disparities in income are not allowed because they increase the income of the least advantaged, but rather because they produce some form of benefit for them. When disparities are found in the distribution of any good, one cannot immediately jump to the conclusion that inequity exists. Instead, the determination of Rawlsian equity rests in whether or not the least advantaged benefit from the disparity in some way.

The framework to evaluate equity this paper established is both easy to use and generalizable. So long as a relationship can be found between the distribution of a good and a socio-economic or demographic factor, the equity of the situation can begin to be evaluated. Similarly, the equity impacts of a *change* in the distribution of a good among groups can be established, as long as data from both before and after the change is available. The framework is less deterministic than it is descriptive; it is not intended to produce a determination of whether or not the situation or change is fair, equitable, or just. Instead, its value lies in enabling people with varying viewpoints and notions of equity to engage in a discussion with the facts of the situation at hand. It also avoids any confusion between equity and equality present in other evaluative techniques. However, its explanatory power is limited in that it only establishes disparities in the distributions of the good in question: it does not help in determining whether or not these disparities are fair in the broader context (in particular, the distribution of burdens).

6.2 Opportunities for Future Study

As previously mentioned, more refined datasets for destinations could enhance and increase the validity of accessibility analyses. Research into existing datasets and methods to generate more precise local information would enhance future work. The Regional Transit Task Force in 2010 stated, “In addition to considering trip origins for people with limited transportation options, consideration should be given to *destinations* for employment, education, healthcare, social services and other civic engagement activities” (emphasis added) (Regional Transit Task Force 2010). A word of caution, though: matching certain socioeconomic groups to specific destinations can err in being too deterministic. For instance, matching low-income populations to low-income jobs very well may be practically beneficial (in terms of transit productivity and economic efficiency), but transit ought to also serve the broader purpose of enabling those populations to achieve more.

Technology is only on the cusp of enabling the everyday use of the methodology described in this paper. The analysis of changes in accessibility before and after a network alteration depends upon the existence of two GTFS feeds, one representing the network before the change and another representing the network after the change. Currently, generating feeds is a labor-intensive process and is only accomplished for finalized networks; feed generation lies at the end of the service change process. To enable analyses of the impacts to accessibility of *proposed* or hypothetical network changes, an easy way to alter and generate GTFS feeds is required. A company called TransitMix is working on such a tool and may have a product capable of producing full GTFS feeds soon (partially powered by a coding group called conveyal) (conveyal n.d.). However, even given that technology, intense computational power is required to generate travel sheds and join them to destination data for thousands of zones across a study

area. For this study, 1,417 start points were input into Hardin's tool to generate travel sheds; python scripting with ArcGIS was used to join the travel sheds to the jobs data. These processes took approximately 300 hours on a high-end desktop computer; additional time was required for data processing using R statistical software. A server with significant distributed processing power would be required to produce data for analysis of a "sketched" network restructure in a reasonable amount of time.

As alluded to previously, the exploration of methods to procedurally alter GTFS feeds to account for traffic congestion and historical schedule adherence (or lack thereof) would enable more realistic accessibility data to be produced. Incorporating the required data and algorithms in a useable tool could greatly benefit transit agencies and their customers in the future.

6.3 The Promise of Accessibility

The ability to get from one point to another in order to do something is one way to define freedom. Transportation represents freedom in motion; it operationalizes freedom and allows it to be experienced. Transit represents one means to achieve these ends, particularly for those who, for whatever reason, cannot access the road network in an automobile. Accessibility analyses measure the ability of people to access opportunity. They communicate the value of the entire transit network to a particular location and the people who reside there. The results of these analyses form a strong basis for measuring equity as part of ongoing policy evaluation and the tracking of strategic goals. For King County Metro specifically, accessibility analyses would nest well as an indicator of progress for its Strategic Plan Goal 2: Human Potential, mirroring the current *access* to transit measures (King County Metro 2013a). The rich indicators of equity resulting from the analyses would greatly benefit King County's annual Determinants of Equity

Report's Transportation category, providing clear signals as to whether the county is moving toward or away from equity.

The methodology to calculate accessibility this paper used can be replicated for any agency that publishes a GTFS feed. (The region's road network would also need to be abstracted for Hardin's tool to calculate path densities; the network abstraction for this paper's study area was provided as part of the package made available to me.) Even until such time as the accessibility impacts of *proposed* network changes can be evaluated, analyses of accessibility from one GTFS feed to the next can indicate to transit agencies whether or not they are moving in the right direction.

Once easy-to-use accessibility analysis tools are available, incorporating them into agencies' business processes will help communicate the value of transit networks to the public. The colorful maps of accessibility represent an aspect of freedom: one's ability to access opportunities to be one's own self-author and to fulfill one's potential. The value of determining the sum total of what transit offers to specific people in specific locations far exceeds any simplistic (or even complex) measure of transit supply. Accessibility analysis offers the best information regarding "who gets" and "what they get" and brings us much closer to truly evaluating the equity of systems.

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Appendix: Methodology Details

This section provides additional details about the data, programs, and steps used to accomplish the accessibility analysis. Additional details, including code snippets, are available upon request from andrew.brick@gmail.com.

Part I: Data

Census block group geometries for King County were retrieved from the US Census Bureau's website (<https://www.census.gov/geo/maps-data/data/tiger-line.html>). Waterbody features were provided by King County GIS (<http://www5.kingcounty.gov/gisdataportal/Default.aspx>, "wtrbdy" shapefile). Census data came from the American Communities Survey, 2009-2013 5-year averages; these data were retrieved using the American FactFinder website (<http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml>). Tables B03002 (columns HD01_VD01 and HD01_VD03), B17021 (columns HD01_VD01 and HD01_VD02), and B22010 (columns HD01_VD01, HD01_VD03, and HD01_VD06) were retrieved at the block group level. Proportions for each of the minority, low-income, and disabled categories were calculated based on the columns referenced. Jobs data was retrieved using the OnTheMap tool at the US Census Bureau's Longitudinal Employer-Household Dynamics website (<http://onthemap.ces.census.gov/>) in the form of a shapefile containing jobs estimates conflated to census block centroids. GTFS feeds were retrieved from King County Metro (<http://metro.kingcounty.gov/gtfs/>) and Sound Transit (<http://www.soundtransit.org/Developer-resources/Data-downloads/Download-Data>).

Part II: Processing

The proportions of low-income, minority, and disabled populations were combined into a single

index as described in the methodology. Each block group under consideration was assigned its corresponding “disadvantage index” score.

Geoprocessing was accomplished using ArcMap. Trip origins consisted of census block group inner centroids and were determined using the Feature To Point tool with the “Inner” checkbox checked. Latitude and longitude for each point were determined and exported to a .csv file. The data in the .csv file was replicated 360 times, and different trip start times – all on the same calendar date (a Monday) were assigned to each copy (6:30, 6:31, etc.). This file constituted an input to Hardin’s travel shed generation tool. Hardin’s tool was then executed, generating 510,120 travel sheds, one for each block group for each time-stamp (1,417 x 360). The tool output travel sheds in raster format, with each pixel classified as either 10, 20, 30, 40, 50, 60, or 255 (representing >60). These numbers represented the grid cells reachable within the stated number of minutes from the trip origin at the trip start time.

To facilitate processing using multiple computers, the set of rasters was split into ten groups. Using an arcpy (python) script, each raster was converted into a set of polygons using the following ArcMap tools: Calculate Statistics (to enable conversion), Raster to Polygon, Dissolve (to account for non-contiguous sheds). For each raster, the areas outside the 60 minute travel shed were discarded. This process generated 510,120 sets of polygons, each consisting of six non-overlapping polygons. Following conversion, each travel shed was spatially joined to the LEHD jobs data using an arcpy script and the ArcMap tool Spatial Join.

The .dbf files of the resulting shapefiles (which contained all of the non-spatial data) were imported into R using the “foreign” package (a total of 3,060,720 rows of data). The gravity model referenced in the paper was then applied to the data; each field of the jobs data was

multiplied by one of six values, depending on whether the travel shed being processed represented 10, 20, 30, 40, 50, or 60 minutes of travel time. The resulting gravity-weighted jobs for each of the six travel sheds corresponding to an individual trip origin and time-stamp were then summed.

The dataset was then split into three parts, one each for the AM, midday, and PM periods. For each of these periods, the jobs data for all of the time-stamps for each individual trip origin were averaged. Agglomeration of the “high school or less,” “some college/college degree,” and “entertainment” categories was accomplished by equally weighting each component jobs category in an average. For instance, the “high school or less” category equally weighted fields cd01 and cd02 from the LEHD jobs dataset. This process resulted in jobs totals for all categories considered (including total jobs / access to opportunity) for each block group under consideration.

The jobs data was then joined to the “disadvantage index” (and later, to the raw proportions of low-income, minority, and disabled residents) for each block group. Standard statistical processing was accomplished in R. Scatterplots and barplots were produced using the “ggplot2” package.

For the secondary study area, the process was repeated using updated GTFS feeds. Differences in accessibility for each block group were calculated by taking raw differences in total gravity-weighted jobs resulting from using each of the “before” and “after” GTFS feeds. The “least advantaged block group” in the secondary study was defined as the block group with the lowest disadvantage index score (Table 12). For Table 14, the “least advantaged block groups” correspond to the block group/s with the highest proportion of low-income, minority, and disabled residents.